

AN EXPERIMENTAL INVESTIGATION OF SHORING SYSTEMS
FOR HIGH-RISE FLAT-SLAB STRUCTURES

by

R. K. AGARWAL

Submitted in partial fulfilment
of the requirements for the degree of
Master of Applied Science

Department of Civil Engineering
School of Graduate Studies
University of Ottawa
Ottawa, Canada

May 1972

ABSTRACT

In high-rise flat-slab structures, the freshly cast floor is supported by shores, which are themselves supported on several previously cast floors. The accumulated load of the freshly placed and partially cured slabs applied by the shores on a lower slab may be larger than the load for which that floor was designed to carry when it had developed its full strength. Additionally at such an early age the concrete slab has not attained its full design strength. The problem is particularly troublesome in multi-storey flat-slab structures, which are designed for a relatively light live load.

Measurements were taken of the construction loads in shores and reshores on two typical high-rise flat-slab structures and the loads applied to the slabs were calculated. The simplified method of analysis, devised by Grundy and Kabaila was used to predict the loads on the slabs of these two buildings. The agreement between the predicted and measured construction loads is good - within 15%.

Using the verified theory the shoring requirements for flat-slab structures are presented for both portland cement and high early strength cement concretes for various ambient temperatures at different rates of construction. Additionally, the reduced shoring requirements for a highly refined shoring stripping procedure are also given.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Dr. N. J. Gardner, Associate Professor, University of Ottawa, whose continued assistance and time to time visits of the experimental sites accounts for the success of this project.

The author also expresses his appreciation for the encouraging cooperation of Mr. Goldsten, Manager of "Eiffel Construction Company" and Mr. Zeidler, General Manager of "Thomas Fuller Construction Company" to carry out the experiments on the apartment buildings at Alta Vista Drive, Ottawa and "Place du Portage", Hull, Quebec, respectively.

The author is also thankful to Mr. Henery and Mr. John Dehamel, works superintendents for their cooperation and assistance during the experiments at the site. For supplying the plans of the typical floors of the structures, the author is grateful to Mr. Vander Velde and Mr. Blare, professional engineers from Adjeleian and Associates Limited and City Hall.

Finally, the author is grateful to acknowledge the financial assistance of the National Research Council of Canada under Grant No. A5645.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	i
ACKNOWLEDGEMENTS	ii
TABLE OF CONTENTS	iii
LIST OF FIGURES AND ILLUSTRATIONS	v
NOMENCLATURE	ix
CHAPTER 1	1
INTRODUCTION	1
CHAPTER 2	6
HISTORICAL REVIEW	6
CHAPTER 3	27
INFLUENCE OF VARIOUS FACTORS ON THE LOAD RATIOS APPLY TO SHORES AND SLABS	27
CHAPTER 4	33
FIELD INVESTIGATIONS	33
CHAPTER 5	62
RECOMMENDED PROCEDURE	62
CHAPTER 6	76
CONCLUSIONS AND SUGGESTIONS	76
LIST OF REFERENCES	79
APPENDICES	
1. SOME OF THE STRUCTURE FAILURES DURING CON- STRUCTION IN CANADA AND U.S.A. DURING THE PAST EIGHT YEARS	85

	<u>Page</u>
2. NUMERICAL ANALYSIS BY NIELSEN	92
3. A. CALCULATION OF DIRECT LOAD ON PROPS (SHORES), APARTMENT BUILDING AT ALTA VISTA DRIVE, OTTAWA	111
B. CALCULATION OF DIRECT LOAD ON PROPS (RESHORES), APARTMENT BUILDING AT ALTA VISTA DRIVE, OTTAWA	117
C. CALCULATIONS OF DIRECT LOAD ON PROPS (SHORES), PLACE DU PORTAGE, HULL, QUEBEC	117
4. MEASURED LOADS ON THE FORMWORK DURING CON- STRUCTION OF THE TWO FLAT SLAB STRUCTURES	118
5. GRAPHICAL REPRESENTATION OF THE LOAD RATIO (ACTUAL AND SHORES-RESHORES)	126
6. THE DETAILED ANALYSIS FOR VARIOUS SHORE/ RESHORE COMBINATION WITH E_c CONSTANT	143
7. PLAN OF THE TYPICAL FLOOR OF THE APARTMENT BUILDING AT ALTA VISTA DRIVE, OTTAWA	158
8. PLAN OF THE TYPICAL FLOOR "PLACE DU PORTAGE", HULL, QUEBEC	160

LIST OF FIGURES AND ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Typical construction cycle adopted by Nielsen	7
2	Summary of the load ratios apply to adjacent components (slabs and forms) for simply supported and clamped beams	8
3	Load ratios apply to adjacent components (slabs and shores), assuming constant E_c	10
4	Load ratios apply to adjacent components (slabs and shores), assuming variable E_c	10
5	Development of E_c and f'_c of normal concrete with age	12
6	Summary of the load ratios apply to adjacent components (slabs and forms) with constant and variable E_c	13
7	Variation of maximum load ratios with flexibility of props	16
8	Effect of number of propped floors on maximum load ratio and converged solution	18
9	Comparison of converged solution with variation of E_c for concrete with time	20
10	Load ratio in props and floors (step-wise construction)	21
11	Comparison of construction and service loads for flat-slab multi storey apartment building	23
12	Taylor's technique of stripping formwork	25
13	Variation of beam or slab flexural strength with compressive strength	31
14	Construction sequence, operation A and B	33

<u>Figure</u>		<u>Page</u>
	<u>APARTMENT BUILDING AT ALTA VISTA DRIVE, OTTAWA</u>	
15	Photographs of apartment building at Alta Vista Drive, Ottawa	36
16	Meteorological conditions during the month of July 1971	37
17	Meteorological conditions during the month of August 1971	38
18	Typical flying-form details	39
19	Shoring unit details	40
20	Typical scaffold arrangement to support the slab between four columns	42
21	Typical reshoring arrangement	43
22- 26	Measurement of loads on the formwork under the slabs at levels 7, 8 13	119-123
27	Calculation of load ratio carried by a floor	45
28	Construction loads on slabs with shored formwork (Analysis based on measurements at site)	46
29	Load ratio apply to adjacent components (shores, reshores and slabs), Theoretical analysis - Variable E_c	47
30	Load ratio apply to adjacent components (shores, reshores and slabs), Theoretical analysis - Constant E_c	48
31	Summary of the load ratio (experimental and theoretical) apply to adjacent components (slabs, shores and reshores)	50
32- 37	Graphs showing the load ratios apply to slabs at levels 7, 8 12	127
38- 43	Graphs showing the load ratios apply to shores and reshores under the slabs at levels 7, 8 12	132

<u>Figure</u>		<u>Page</u>
	"PLACE DU PORTAGE", HULL, QUEBEC	
44	Photographs of apartment building "Place du Portage", Hull, Quebec	53
45	Meteorological conditions during the month of September 1971	54
46	Details of typical shoring arrangement	55
47	Typical shoring arrangement to support the slab	57
48	Measurement of loads on the formwork under the slab at level 19	124
49	Measurement of loads on the formwork under the slabs at levels 20, 21 and 22	125
50	Load ratio apply to adjacent components (shores and slabs) - Analysis based on measurement at site	58
51	Load ratio apply to adjacent components (shores and slabs) - Theoretical analysis, Variable E_c	59
52	Summary of the load ratio (experimental and theoretical) apply to adjacent components (shores and slabs)	60
53- 55	Graphs showing the load ratios apply to slabs at levels 19, 20 and 21, respectively	137
56- 58	Graphs showing the load ratios apply to shores under the slabs at levels 19, 20 and 21, respectively	140
59	Different strengths (%) against time	66
60	Summary of theoretical and construction L.R. for various shore/reshore combination and with constant E_c	67
61	Recommended shoring and reshoring requirement with maximum three levels of shores and temperatures 70°F to 85°F	68
62	Compressive strength of concrete at low temperatures (55°F and 40°F)	70

Figure

Page

GRAPHS SHOWING THE EFFECT OF LOW TEMPERATURES
ON THE COMPRESSIVE STRENGTH OF CONCRETE IN
TERMS OF CONCRETE STRENGTH (%) AT 73°F:

		71
63	Concrete with type I cement	71
64	Concrete with type III cement	71
65	Recommended shoring and reshoring require- ments at low temperatures (55°F and 40°F) (with maximum 3 levels of shores)	72
66	Recommended shoring and reshoring require- ments using the technique of slackening and tightening the shores with maximum 3 levels of shores and temperatures 70°F to 85°F	74
67	Recommended shoring and reshoring require- ments at low temperatures (55°F and 40°F) using the technique of slackening and tightening the shores (with maximum 3 levels of shores)	75

NOMENCLATURE

ACI	= American Concrete Institute
Bal	= Balancing
B.C.	= Boundary Conditions
C.E.T.	= Civil Engineering Transactions
C.O.	= Carry Over
Conc.	= Concrete
Const.	= Construction
CSA	= Canadian Standards Association
CSIRO	= Commonwealth Scientific and Industrial Research Organization
D.L.	= Dead Load
E.N.R.	= Engineering News Record
L.L.	= Live Load
L.R.	= Load Ratio
q	= $\frac{p f_y}{f'_c}$
P	= $\frac{A_s}{b d}$
T	= Time cycle of construction per floor

CHAPTER 1

INTRODUCTION

The design of a structure presents a two-fold problem. In the first instance, a structure has to be designed so that it is strong enough and stiff enough to perform its desired function effectively during its service life. But in addition, a successful structural design must also consider the safety of the structure during its construction, namely formwork, scaffold and props, etc., to resist the construction loads imposed upon these items and the structure itself. These should be considered as carefully as the service loads in the design of the structure.

In olden days buildings were not as high as today, and normally the formwork was built in place, used once and scrapped. But today's structures and their formworks are not the same. The design manual "Formwork of Concrete"⁽⁵¹⁾ states that the formwork cost may range from 35 to 60 percent of the cost of concrete structure. Since formwork is an appreciable proportion of the cost of the concrete building, the former practice of single use forms cannot be adopted. To minimize the high cost of formwork, continuous reuse of the forms is

very essential, which leadsto the increasing trends of pre-fabrication assembly and erection by mechanical means.

In addition, to make earlier use of the structure, the aim of the (developer) contractor is to complete the construction of the structure as early as possible. But safety should not be sacrificed to meet this requirement. It is seen that premature removal of forms and shores, or improper and careless practices in reshoring have caused numerous failures or defects such as sagging or cracking in complete structure, throughout the history of concrete construction. Inadequate size or spacing of reshores may bring the danger of collapse during construction. Of course when a building collapses during construction, it is easy to blame the formwork, since it and much of the other evidence are covered by wreckage. Such an explanation sometimes conveniently masks the real cause of trouble, but formwork has trusly been at fault in many cases of failure. (Appendix 1):

Appendix 1 summarizes some of the construction failures in Canada and the United States of America, during the past eight years. These failures were caused partially, if not fully, due to careless practices of shoring and reshoring. From which it is evident that the main causes of formwork failure are:

1. Inadequate bracing and high posts without lateral supports.
2. Premature form removal.

3. Insufficient falsework support
4. Low strength of concrete (normally during cold weather) - which causes unexpected high loadings at the shores or reshores.
5. Poor bearing capacity of the soil beneath the lower level of supports which causes the formwork to settle with consequent collapse of the slab.

The formwork failures, cited in Appendix 1 refer only to the instances of structure collapse, usually with death as a result, and not to the vastly greater number of occasions when some feature of formwork or its use has caused damage in the building less than collapse. Due to the large number of "formwork" failures the actual loads on formwork shoring systems need to be determined before new procedures or shoring system can be accepted.

In the present age of fast construction of high rise buildings, the freshly casted floor is supported by shores, which in turn are supported on several previously casted floors. The construction load in these supporting floors may appreciably exceed the design loads. The problem is particularly troublesome in multi-storey flat-slab structures, which are designed for a relatively light live load. The accumulated load of the slabs freshly placed and partially cured together with the construction live load may be larger than the load for which a floor is designed to carry when it has developed

its full strength. Usually only part of that strength is developed when construction of the next storey begins.

Hence it was desired to derive a shoring and reshoring system and construction sequence such that the loads on any slab are less than some desired function of the "design" load of that slab, taking an account of the age of that slab, which involves knowledge of the following:

1. Knowledge of the gain of concrete strength and stiffness with the age of the slab.
2. Good approximation of the load analysis on different members of the partially completed building. It should be borne in mind that the distribution of the moments in the slabs due to concentrated loads transferred through the shores or reshores will be different from the assumed design distribution.
3. The redistribution of the loads during the process of reshoring will depend to a greater extent on the tightening of the reshores, and this tightening factor is difficult to evaluate exactly. Over-tightening of the reshores will definitely increase the load on the lowest floor in the sequence, so it is advisable to give some 'factor of safety' in the design against this fact of manual tightening or reshoring.

The object of this investigation was to determine the actual load ratios applied to the slabs and shores-reshores during construction and to compare these with the theoretical ones and subsequently to determine a shoring schedule in practice for different rates of construction, types of cements and ambient temperatures. It was assumed that the structural detailing of the formwork itself is easy once the loads in the formwork are known. Hence this thesis is concerned only with the loads acting on the formwork, shores and the slabs.

Thus the loads carried by the shores and reshores during construction of the two high-rise flat-slab buildings - one twenty-two floor apartment building at Alta Vista Drive, Ottawa and the other twenty-six stories "Place Du Portage" in Hull, Quebec were measured. Load measurements on shores-reshores were taken over a complete construction cycle namely seven floors (7th floor slab to 13th floor slab) on the first building and from 19th floor slab to the 22nd. floor slab on the second structure.

CHAPTER 2

HISTORICAL REVIEW

Faster progress schedules in the construction of highrise concrete buildings require a careful design of the formwork. The necessity of good formwork design and control of the construction cycle was noted by Mr. Emrik Lindman, a Swedish engineer in 1930. In 1949 a preliminary report entitled an "Investigation of Load Distribution between Reinforced Concrete Floor Slab and Their Formwork" was written by Knud E.C. Nielsen and was published in Bulletin No. 19 of the Swedish Cement and Concrete Research Institute. Nielsen's⁽⁵⁴⁾ final report was published in the year 1952, in which he presented a detailed analysis of the interaction between formwork and floor slabs under loads, applied to the system by placing fresh slabs and by removing props from beneath the lowest slab in the system as shown in Figure 1.

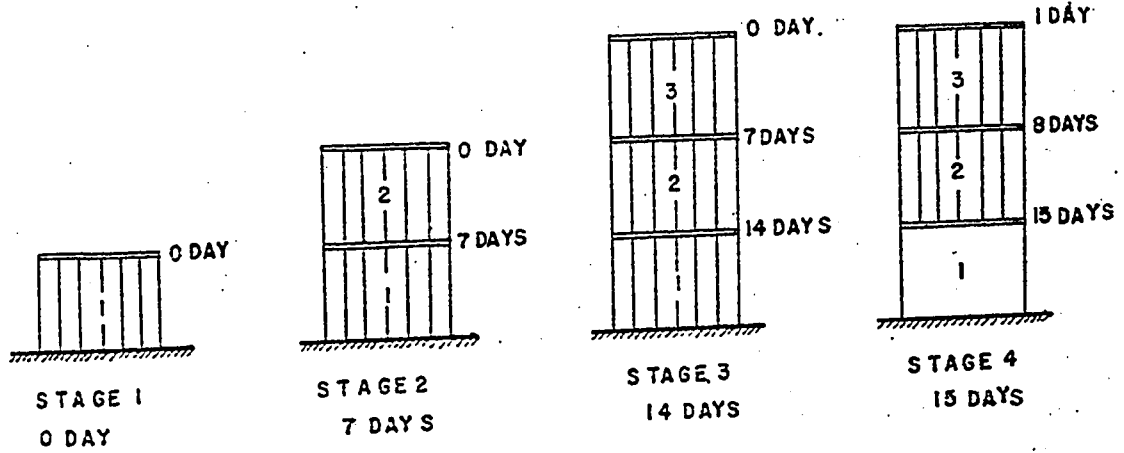
The analysis is confined to a rectangular slab subjected to any arbitrary boundary conditions. The characteristic functions and characteristic values of the slabs are assumed to be known. The maximum load ratio* obtained by Nielsen on a slab was 2.66 on slab No. 2 at stage 7 (see Figure 2). The calculations involved in his analysis are lengthy and can not be applied readily to individual cases. The derivations of his method of calculations is shown in Appendix 2

* The loads carried by shores, reshores and slabs are expressed as a factor by which, the self weight of the slab plus formwork, must be multiplied to give the construction load. This factor is referred to as the "load factor."

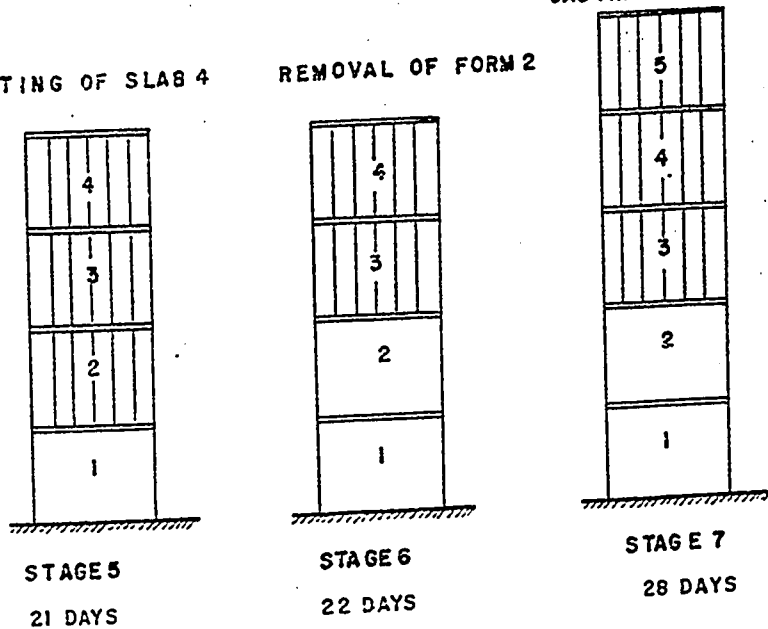
7-DAY CYCLE, THREE LEVELS OF SHORES

($m=3, N=1$)

CASTING OF SLAB 1 CASTING OF SLAB 2 CASTING OF SLAB 3 REMOVAL OF FORM 1



CASTING OF SLAB 4 REMOVAL OF FORM 2 CASTING OF SLAB 5



TYPICAL CONSTRUCTION CYCLE
ADOPTED BY NIELSEN

FIG. NO. 1

SUMMARY

STAGE/DAYS	B. C.	FORM - 1			2			3			4			5		
		AGE	SLAB	FORM	AGE	SLAB	FORM	AGE	SLAB	FORM	AGE	SLAB	FORM	AGE	SLAB	FORM
1/0	S.S (K=0.3)	0	0	1.00												
	CL (K=0.3)	0	0	1.00												
	CL (K=0.8)	0	0	1.00												
2/7	S.S (K=0.3)	7	0	2.04	0	0	1.00		0	1.00						
	CL (K=0.3)		0.37	1.63		0	1.00		0	1.00						
	CL (K=0.8)		0.09	1.91		0	1.00		0	1.00						
3/14	S.S (K=0.3)	14	0.16	2.76	7	0.08	1.92		0	1.00						
	CL (K=0.3)		0.69	1.84		0.47	1.53	0	0	1.00						
	CL (K=0.8)		0.35	2.42		0.23	1.77		0	1.00						
4/14	S.S (K=0.3)	14	1.84	-	7	1.16	0.84		0	1.00						
	CL (K=0.3)		2.00	-		1.00	1.00	0	0	1.00						
	CL (K=0.8)		1.89	-		1.11	0.89		0	1.00						
5/21	S.S (K=0.3)	21	2.22	-	14	1.58	1.22		0.20	1.80		0	1.00			
	CL (K=0.3)		2.15	-		1.36	1.15	7	0.49	1.51	0	0	1.00			
	CL (K=0.8)		2.19	-		1.52	1.19		0.29	1.71		0	1.00			
6/21	S.S (K=0.3)	21	1.00	-	14	2.28	-		0.72	1.28		0	1.00			
	CL (K=0.3)		1.00	-		2.16	-	7	0.84	1.16	0	0	1.00			
	CL (K=0.8)		1.00	-		2.24	-		0.76	1.24		0	1.00			
7/28	S.S (K=0.3)	28	1.00	-	21	2.66	-		1.14	1.66		0.20	1.80		0	1.00
	CL (K=0.3)		1.00	-		2.31	-	14	1.20	1.31	7	0.49	1.51	0	0	1.00
	CL (K=0.8)		1.00	-		2.54	-		1.17	1.51		0.29	1.71		0	1.00

FIG-NO. 2 LOAD RATIOS APPLY TO ADJACENT COMPONENTS (SLABS & FORMS) REF. NO. 54
FOR SIMPLY SUPPORTED & CLAMPED BEAMS (K=0.3 & 0.8, m = 3, N=1)

NO. 10 ALLENDALE UNIT
ANYHILL, CHINA

In 1963 Grundy and Kabaila⁽⁴⁴⁾ developed a simplified method to determine the loads imposed on the formwork and on the individual slabs in any system of forms - shores and slabs. The most significant difference between their approach and that of Nielsen is the assumption that the rigidity of the props may be regarded as infinite by comparison with that of the slabs. This enables loads imposed on the system, either by casting of new slabs or by removal of the props, to be distributed between the slabs in direct proportion to their flexural stiffness, which in a floor of equal dimensions results in a distribution according to the modulus of elasticity of the concrete (E_c) at the time that the loads are applied.

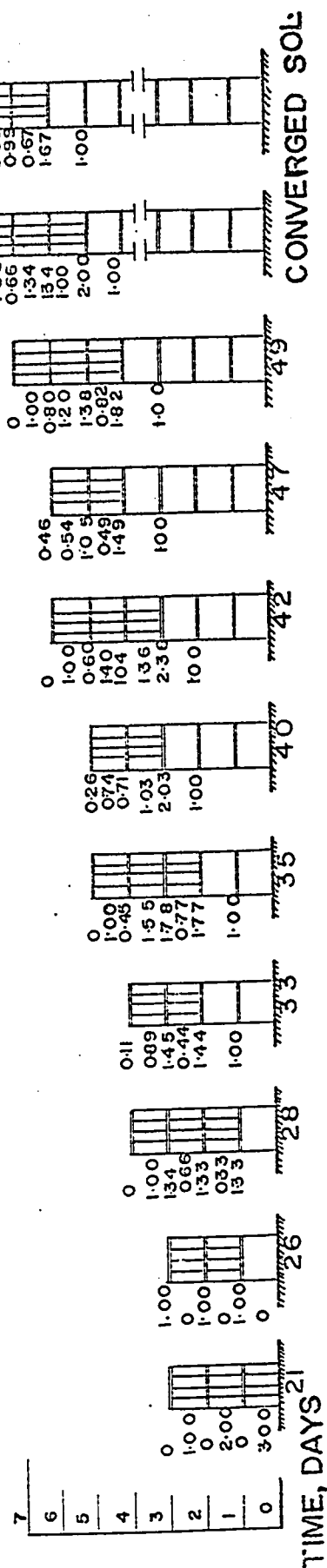
In a typical multi-storey construction, normally the following two alternating operations which control the loads being applied to the slabs.

1. Placing a fresh slab, usually rising at the rate of 1 or 2 floors a week, and
2. Removing the lowest level of shores, when the youngest floor has the age of 1 to 5 days (i.e. $N = 1$ to 5 days), where N is the time between placing of a fresh slab and the removal of the props from above the lowest slab in the system.

In the analysis presented by Grundy and Kabaila, zero time is reckoned at the pouring of the footings. The rate of construction is assumed as one floor a week with $N = 5$ days. As shown in Figure 3, the first, second and third floors are

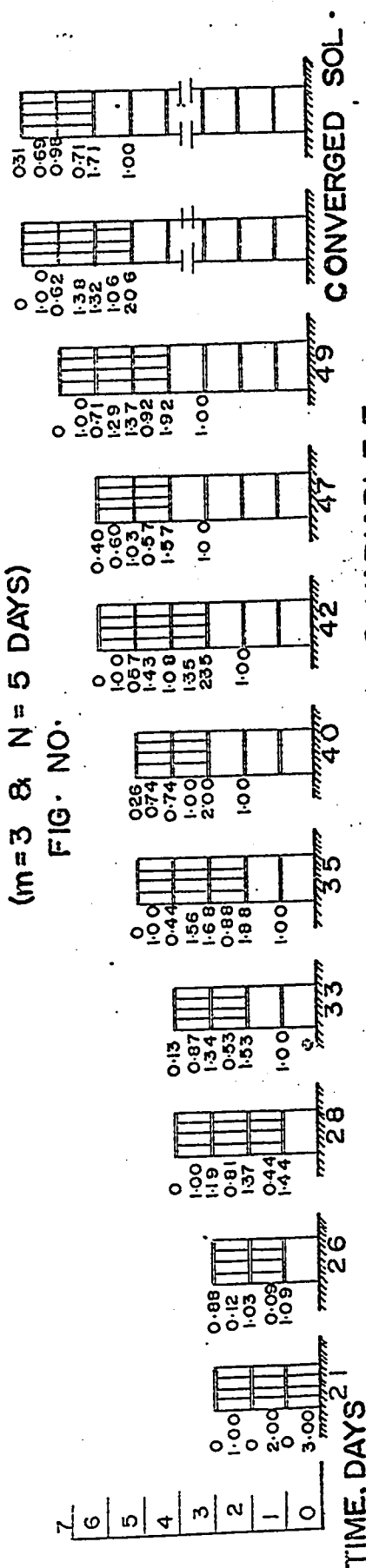
TYPICAL CONSTRUCTION CYCLE ADOPTED BY GRUNDY & KABAILA

LOAD RATIO APPLY TO ADJACENT COMPONENTS (SLABS & SHORES)



ANALYSIS ASSUMING CONSTANT E_c
($m=3$ & $N=5$ DAYS)

FIG. NO. 4



ANALYSIS ASSUMING VARIABLE E_c
($m=3$ & $N=5$ DAYS)

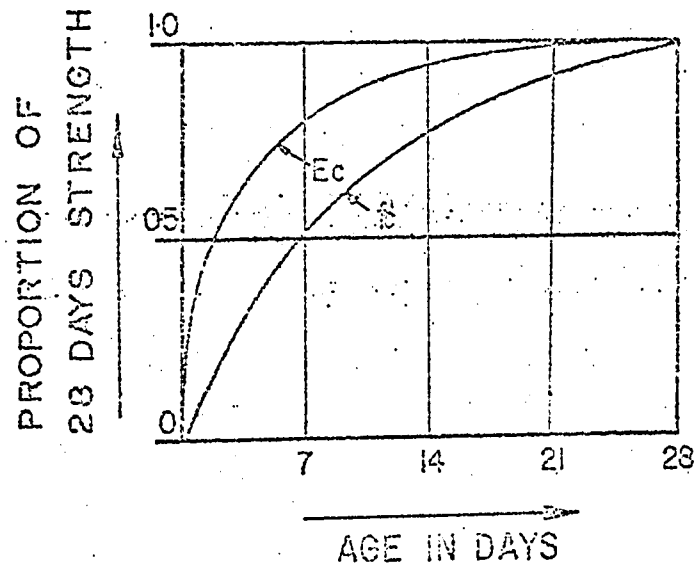
FIG. NO. 4

REF. NO. 44

cast at the time of 7 days, 14 days and 21 days respectively (operation 1), after the foundation is poured. The numbers shown in the figure are the load ratios (a factor by which the self weight plus formwork must be multiplied) carried by the slabs or shores at different stages. As three levels of shores are employed, so the lowest level of shores (one touching the ground floor) would be removed to the third floor at the time of 26 days (operation 2). When the props are removed, the three floors undergo the same deflection and the total weight of the three floors will be distributed between them in proportion to their relative stiffnesses.

As stated before, the flexural stiffness of an uncracked section is assumed to be directly proportional to the modulus of elasticity (E_c) of the concrete. A typical development of E_c and concrete crushing strength (f'_c) in terms of 28 days strength is shown in Figure 5, which clearly indicates that the rate of development of E_c with time is faster than that of f'_c , and after the first few days, E_c is effectively constant with time. Grundy and Kabaila in their analysis (see Figure 6) have shown that the load ratios obtained with constant E_c and variable E_c are very close, and hence the error introduced by the assumption that the relative stiffness of the floors are equal is not appreciable.

As shown in Figure 3 until the ground shores are removed, all the loads are transmitted through the shores to



DEVELOPMENT OF E_c & f'_c OF NORMAL CONCRETE
WITH AGE

FIG. NO. 5

RIF. NO. 44

STAGE DAYS	FORM 1		2		3		4		5		6		B.C.
	AGE	SLAB	AGE	SLAB	AGE	SLAB	AGE	SLAB	AGE	SLAB	AGE	SLAB	
1/7	0	1.00											
2/14	7	2.00	0	1.00									
3/21	14	3.00	7	2.00	0	1.00							
4/26	19	1.00	12	1.00	5	1.00							
5/28	21	1.33	14	1.37	7	1.34	0.66	0	1.00				
6/33	26	1.00	19	1.53	12	1.34	0.53	5	1.00				
7/35	28	1.00	21	1.88	14	1.68	0.88	7	1.00				
8/40	33	1.00	26	1.00	19	2.00	-	12	0.74	1.00	0.26	0.74	
9/42	35	1.00	28	1.00	21	2.36	-	14	1.04	1.36	0.60	1.40	0 1.00
						2.35	-	14	1.08	1.35	0.57	1.43	0 1.00

FIG.NO.6. LOAD RATIOS APPLY TO ADJACENT COMPONENTS (SLABS & SHORES)

(WITH CONSTANT & VARIABLE F_c)

UNIVERSITY OF ALABAMA

the rigid foundation. At 26 days, the shores at the ground level are removed and the shore force (3.00) is distributed equally between the slabs at levels 1, 2 and 3. At 28 days when a new slab at level four is cast, its weight (1.00) is distributed equally between the slabs at level 1, 2 and 3. Now at 33 days when the shores at level 1 are removed, its force (0.33) is distributed equally between slabs at levels 2, 3 and 4 and so on. It is observed that the maximum load ratio obtained is 2.36 on slab of age 21 days at level 3, against the value 2.66 obtained by Nielsen (see Figures 2 and 6) at a slab age of 21 days.

Both the above analyses, presented by Nielsen and Grundy-Kabaila, are based on the following assumptions:

1. The shrinkage and creep of the concrete in the slabs may be disregarded for the purpose of analysis, and that the slabs behave elastically.

2. The props supporting the slabs and formwork may be regarded as a continuous uniform elastic support; the elastic properties of which may be expressed by a coefficient K , where K = load intensity that produces unit deformation of the support. In the method described by Grundy and Kabaila K is assumed as infinite, which greatly simplifies the analysis; as each slab will deflect equally and additional load is shared by the slabs in proportion to their flexural stiffness.

3. Slabs are assumed to be supported from a completely rigid foundation.

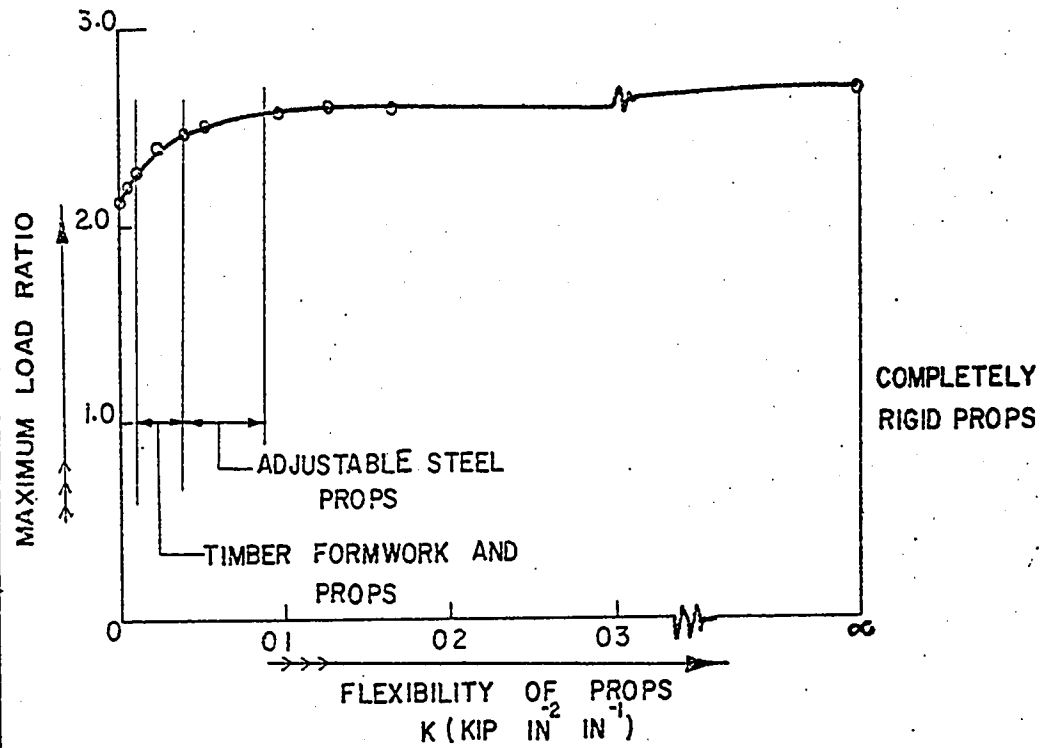
4. E_c , the modulus of elasticity of concrete, which increases with time is taken into account. (Though after a few days, the variation of E_c with time is not appreciable.) (see Figure 5).

5. Torsional moments and shearing forces in the formwork are neglected and hence the reaction produced by a support is assumed to be directly proportional to its compressive load.

All these basic assumptions are in, general, conservative, flexibility in the props or foundation, redistribution of the loads between operations, and creep in the concrete, should all tend to reduce the maximum load ratios. The only case when these assumptions are not conservative is if the foundation slab settles while supporting a freshly cast first floor.

It is observed by comparing the results of the analyses presented by Nielsen and Grundy-Kabaila, that the difference in numerical values of load ratio is not great. The most significant difference between the two approaches is the assumption of props, whose rigidity is regarded as infinite compared with that of the slabs by Grundy and Kabaila, whereas Nielsen has taken this factor into account. But Beresford (2), plotted the maximum load ratios (proportion of the self weight of the slab plus formwork) against K (which is the stiffness of the supports expressed

UNIVERSITY OF OTTAWA
OTTAWA, ONTARIO



VARIATION OF MAXIMUM LOAD RATIOS
WITH FLEXIBILITY OF PROPS

FIG. NO. 7 REF. NO. 2

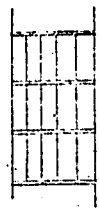
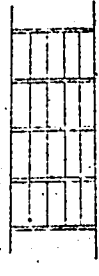
LOAD RATIO = (PROPORTION OF THE SELF WEIGHT OF THE SLAB PLUS FORMWORK)

K = STIFFNESS OF THE PROPS, EXPRESSED AS THE LOAD INTENSITY
REQUIRED TO PRODUCE UNIT DEFORMATION.

as load intensity required to produce unit deformation) see Figure 7. The range of K over which timber supports and adjustable steel props apply are also shown in this figure. From the graph (see Figure 7) it is clear that no real benefit can be derived by varying the flexibility of the props within critical limits. So it is apparent that the assumption of completely rigid props (assumed by Grundy and Kabaila) for the purpose of analysis is justifiable.

It is observed by Grundy and Kabaila that the maximum loads are always carried by the last slab cast in the system before the shores at the lowest level are removed. Figure 8 shows the maximum load ratios obtained by employing different level of shores (two to five level of shores). It is quite evident from this figure that the increase in the level of shores does not affect the converged load ratios on the slabs, but the maximum load ratios are increased by increasing the number of levels of shores. But this increase in the maximum load ratio of the slab may be balanced by the increase of its age.

In 1964, Beresford⁽²⁾ tried to control the high construction loads on flat slabs in multistorey building by employing the characteristic properties of concrete. He felt that the risk of damaging the floor slab due to high loading

				
NO.OF PROPE D FLOORS	2	3	4	5
SLAB SUPPORTING THE MAX. LOAD	2 nd .	3 rd .	4 th .	5 th .
MAX. LOAD RATIO	2.25	2.35	2.45	2.50
AGE OF THE SLAB CARRYING THE MAX. LOAD RATIO	2T	3T	4T	5T
MAX. CONVERGED LOAD RATIO	2.00	2.00	2.00	2.00

EFFECT OF NO. OF PROPE D FLOORS
ON
MAX. LOAD RATIO AND CONVERGED
SOLUTION

FIG. NO. 8

T = TIME CYCLE OF CONSTRUCTION
PER FLOOR

during construction can be reduced when concrete which attains strength and stiffness at earlier ages than normal concrete, is used. Additives, high early strength cements (type III) and curing techniques are possible methods of improving these characteristics of concrete.

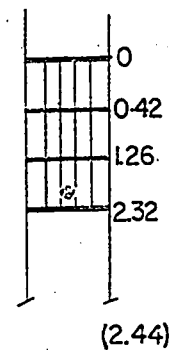
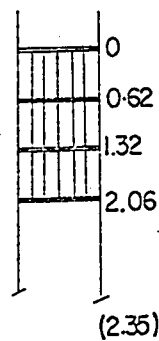
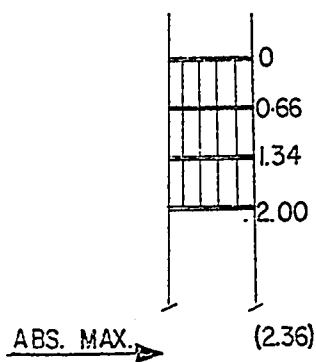
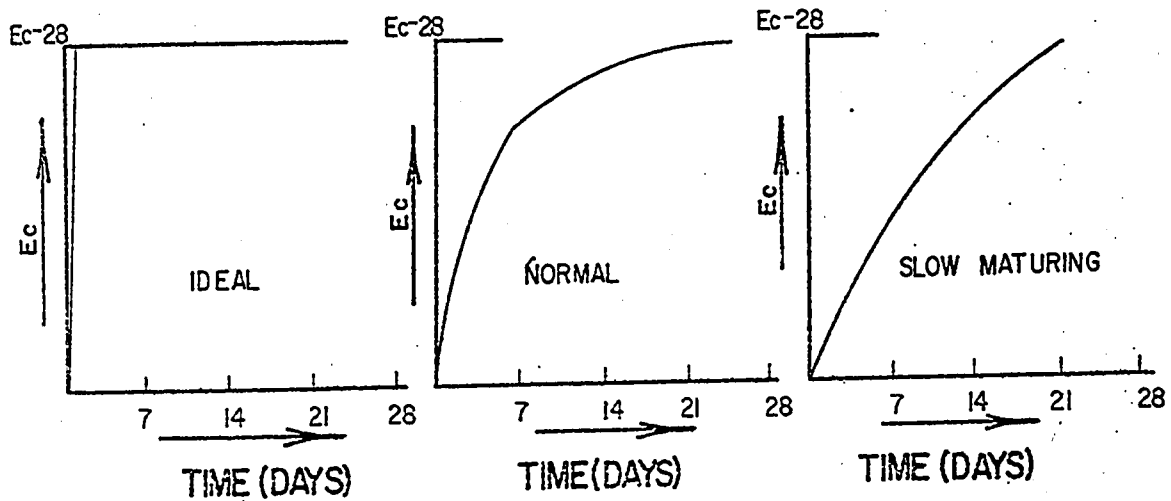
He selected the following three types of concretes.

1. Theoretically perfect concrete which attains full stiffness shortly after placing.
2. Normal concrete as would normally be used, and
3. Concrete selected as particularly slow in gaining stiffness.

The converged solutions (employing three level of shores in all the cases), which results from the above three sets of concrete are shown in Figure 9.

The results clearly indicates that there is hardly any difference in the analysis between the first two cases. The only benefit which is to be gained from high early strength concrete will be due to its ability to resist the stresses imposed at an early age of the slab. The solution obtained with slow maturing concrete indicates a significant increase in the imposed load on the lowest floor, however, the converged solution is affected more than the maximum value. Thus this type of concrete is out of question in fast construction.

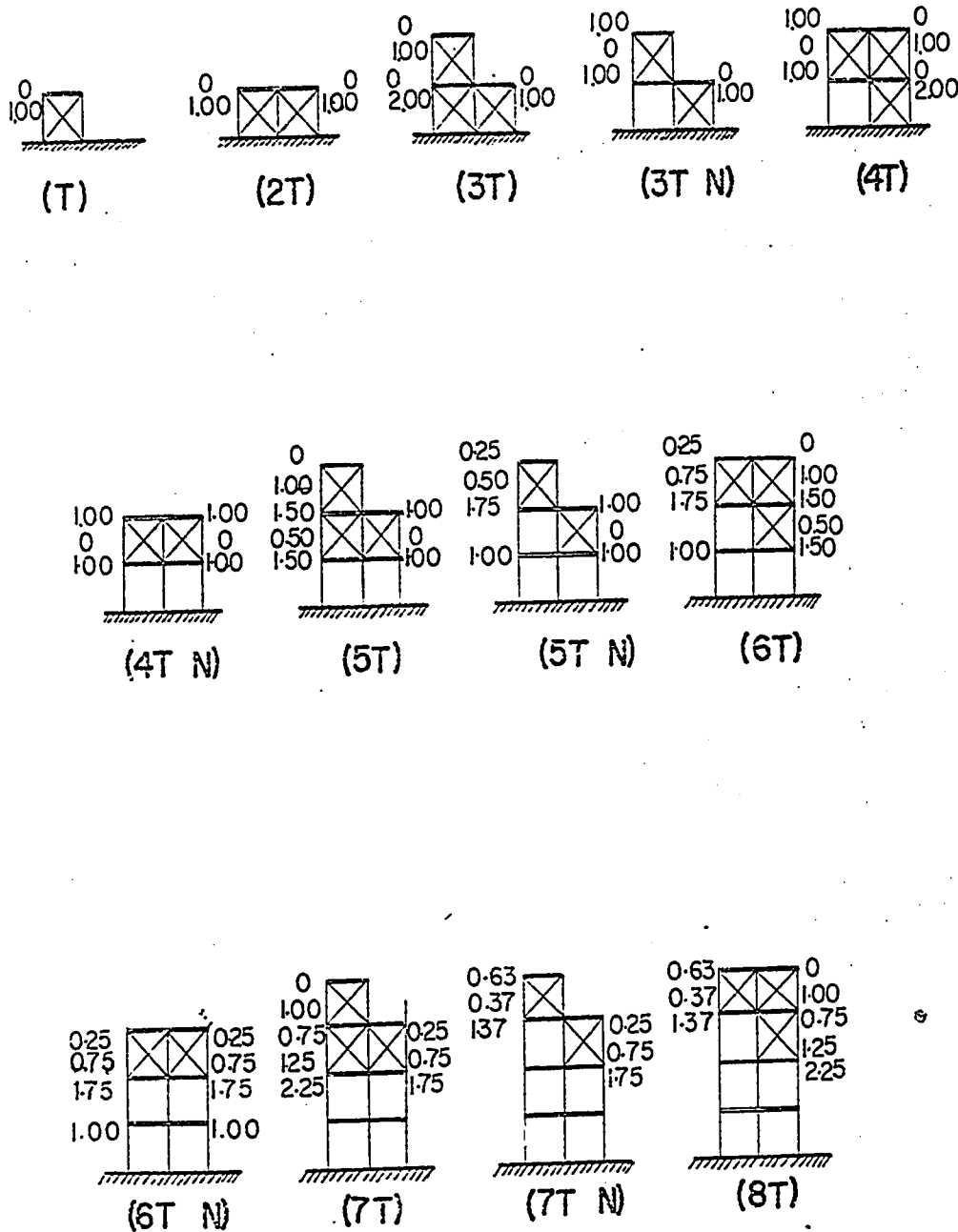
In 1965, Blakey and Beresford⁽³⁾ suggested a construction sequence, in which the progress is stepwise instead of uniformly vertical (see Figure 10). They employed two levels



COMPARISON OF CONVERGED SOLUTION ($N=5$ DAYS & $m=3$)
WITH VARIATION OF E FOR CONCRETE
WITH TIME

FIG-N09

REF NO. 2



STEP-WISE CONSTRUCTION
LOAD RATIO IN PROPS & FLOORS
FIG. NO. 10.

REF. NO. 3

T = TIME CYCLE OF CONSTRUCTION PER FLOOR.

N = TIME BETWEEN PLACING OF A FRESH SLAB AND THE REMOVAL OF THE PROPS
FROM ABOVE THE LOWEST SLAB IN THE SYSTEM.

of shoring, the maximum load ratio is the same as obtained by Grundy and Kabaila (i.e. 2.25). The only advantage by adopting this construction sequence is that the maximum load ratio is experienced by the slab, when its age is 4T instead of 2T in the case of uniform vertical construction. However, the rate of construction is slower and hence this method of construction is not very common.

By the analysis, so far described, it is seen that the construction loads in a concrete flat slab structure in which upper floors are shored from the lower floors may exceed design loads by a considerable margin. Take the example of a normal flat slab multistorey apartment building, with a slab thickness of 8", designed for a DL of 100 psf and a LL of 70 psf (assuming the weight of normal concrete as 150 lbs/cu.ft). If a 7-day construction cycle is adopted and 3 levels of shores are employed, the maximum critical load sustained by the slab will be 258.5 lbs/sq.ft at a slab age of 21 days (see Figure 12), which means overloading by about 60% compared with the design using working stress design method. If the slab had been designed by the ultimate strength design method the slab would be at the point of failure. Obviously, the load on the slab is unacceptably high regardless of the design philosophy.

Taylor⁽⁶⁴⁾ in 1967 came out with an ingenious program of formwork stripping to reduce the critical load on slabs during construction. He suggested that if the form-

EXAMPLE ON LOAD DURING CONSTRUCTION

CONSTRUCTION LOAD (LBS. PER SQ. FT.)			SERVICE LOAD (LBS. PER SQ. FT.)	
ITEM	TYPICAL FLOOR	MAXIMUM AT LEVEL 3	ITEM	DESIGN LOAD
8" SLAB	100	100	8" SLAB	100
FORM-WORK	10	10	FINSHES	15
SUB-TOTAL	110	110	PARTITIONS	15
LOAD RATIO	2.06	2.35	LIVE LOAD	40
TOTAL (AT 21 DAYS)	226.6	258.5	TOTAL (AT 28 DAYS)	170.0

REMARK CONSTRUCTION LOAD IS ABOUT 60% MORE THAN DESIGN LOAD

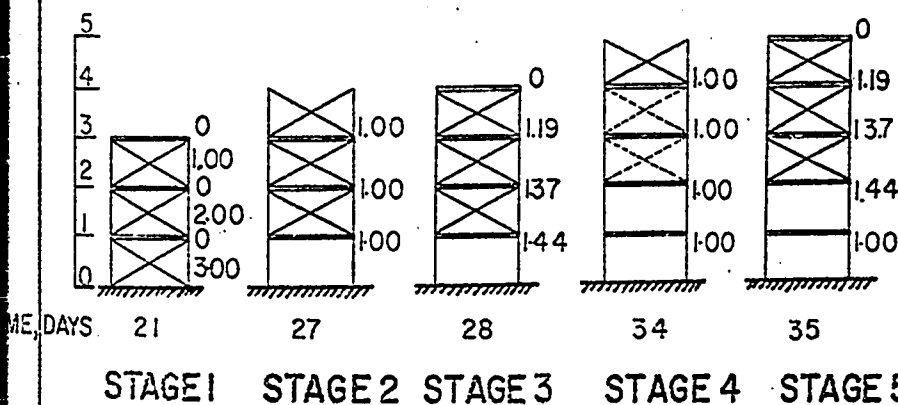
COMPARISON OF CONSTRUCTION & SERVICE LOADS
FOR
FLAT SLAB MULTISTORY APARTMENT BUILDING
(7 DAY CYCLE & $m=3$)

FIG. NO-11

work stripping programme employed the technique of slackening and tightening the shores by rotating the threaded collar on the middle part of the props, the slab shoring load ratio can be reduced to a great extent. Making the same assumptions adopted by Grundy and Kabaila and using the special technique of slackening and tightening, he showed that the maximum load ratio never exceeded 1.44 at slab age 21 days (see Figure 12).

In this procedure when the shores are slackened (see Figure 12, stage 4), each slab takes its own weight and no load will be transferred from the upper slabs to the lower slabs through the shores. After the shores are tightened up and a new slab is poured at the top (stage 5), then the weight of the new slab will be distributed to the lower floors as shown in stage 3 at 28 days. Thus repeating this process of slackening and tightening every time before a new slab is cast (of course after stage 3), the maximum load ratio will never exceed 1.44. Taking the same example shown in Figure 11, the maximum load carried by the slab at the age of 21 days will be 158.4 lbs/sq.ft during construction against 170 lbs/sq.ft design load at 28 days, which is quite reasonable. The only disadvantage in this technique is that it needs to be handled by skilled labourers and constant supervision by some responsible person is desirable throughout the construction.

ASSUMING 7-DAY CYCLE, THREE LEVELS OF SHORES
($m=3$, $N=6$ DAYS & VARIABLE E_c)



STAGE	TIME (DAYS)	OPERATION	REMARK
1	21	POUR LEVEL 3	LOAD RATIO NEVER EXCEEDS 1.44
2	27	REMOVE LOWEST SHORIN & PLACE SLAB AT LEVEL 4	
3	28	CAST SLAB AT LEVEL 4	
4	34	REMOVE LOWEST SHORING & PLACE FOR LEVEL 5 SLACKEN TOMS UNDER LEVEL 4, THEN UNDER LEVEL 3, TIGHTEN TOMBS.	
5	35	POUR SLAB AT LEVEL 5	
REPEAT STAGES 4 & 5 FOR UPPER SLABS.			

TAYLOR'S TECHNIQUE OF STRIPPING
FORM-WORK
FIG. NO. 12

REF. NO. 64

It is concluded that the analysis for load ratios applied to adjacent components (slabs and props) in a flat-slab multistorey construction presented by Grundy and Kabaila is quite easy to adopt from practical design point of view. The analysis presented by Nielsen, involves a lot of mathematics and is very cumbersome and lengthy which renders it undesirable in practice.

By using Grundy and Kabaila's method Taylor further suggested that the slab-shoring load ratio may be reduced by employing the technique of slackening and tightening the shores.

The method presented by Grundy and Kabaila is easy to use and theoretically valid, provided the basic assumptions are valid. However, very little direct experimental evidence is available on which the validity or accuracy of the results calculated using Grundy and Kabaila method can be judged. Experimental data is needed to confirm the analysis. Thus attempts are made in this report to investigate the load distribution during construction on two high-rise buildings, one in Ottawa and one in Hull, Quebec.

UNIVERSITY LIBRARY
OTTAWA, ONTARIO

CHAPTER 3

INFLUENCE OF VARIOUS FACTORS ON THE LOAD

RATIOS APPLY TO SHORES AND SLABS

The loads on adjacent components (props and slabs) during construction of multistorey flat slab structures will normally be influenced and controlled by the factors outlined below:

1. Flexibility of Supports

Beresford⁽²⁾ has already shown that no real benefit can be derived by varying the flexibility of the props within practical limits (see Figure 9). It is also apparent that the assumption of completely rigid props for the purpose of analysis is justifiable.

2. Creep

Creep deformation of concrete may be expected to influence the distribution of load in slab/formwork systems. Nielsen⁽⁵⁴⁾ has suggested that this factor may be ignored because upper slabs, loaded when fairly young and which, therefore, may be expected to show a high creep rate are under small stresses, whereas the lower more highly stressed slabs will show a lower creep rate, because they are older. It is expected that the high creep rate and low stress for the upper slabs will give a deformation roughly equal to that

from a low creep rate and high stress of the lower slabs. This hypothesis has been used because it greatly simplifies the analysis and the information on the creep rate of concrete at very early ages is not available.

3. Relative Stiffness of Floors

Grundy and Kabaila⁽⁴⁴⁾ have assumed for the sake of simplicity that the relative stiffnesses of the floors are about unity. Comparison with the more refined analysis presented by Nielsen⁽⁵⁴⁾ has shown that the errors introduced by this assumption are in some way self compensated so that the estimation of maximum prop or floor loads is not greatly in error. While the concrete section is uncracked, the stiffness is related to the modulus of elasticity of the concrete. By comparison with a graph of crushing strength with time, a graph of modulus of elasticity against time (see Figure 5) shows a much more rapid early rise, followed by a levelling off, so that after about three days, the change in elastic modulus for the next few weeks is not great. Ho's⁽⁴⁷⁾ work showed that the ratio of flexural rigidity to flexural strength was approximately constant with respect to time and hence the effect of variable flexural rigidity and slab strength could be ignored.

4. Number of Levels of Shores

It is observed by Grundy and Kabaila⁽⁴⁴⁾ that the maximum loads are always carried by the last slab cast in the

system before the shores at the lowest level are removed. It is also mentioned by them that the maximum construction load increases with the increase of propped floors.

5. Construction Cycle

N represents the time between placing of a fresh slab and the removal of the props from above the lowest slab in the system. The values of N used in construction cycles is usually from 1 day to 6 days (if the casting rate is a slab every 7 days). Actually the choice of N is based upon the time requirement to remove and reinstall formwork at higher levels. Both the stiffness and strength of a slab increase with age, however the stiffness increases faster than strength. Thus initially the load on the slab increases faster than the load capacity of the slab, if the construction time is reduced. The only advantage of using more levels of shores is to allow the slabs to gain as much strength as possible. Generally the props are left at the lowest level as long as possible after placing a fresh slab.

5. Tightening of Reshores

The method of stripping formwork is significant, since most methods require removal and replacement of shores. The general effect of stripping formwork by this method is to reduce the loads on the slabs beneath and to increase the load on the slabs above (by a corresponding amount). During this

process of reshoring at site, the reshores are generally tightened up; the degree of tightening will normally affect the loads in the props and thus in the slabs. Normally what is required is that immediately after stripping the formwork, the shores should be replaced only with a light compressive force in them to hold them in place. But the degree of tightening the props is difficult to control at site. Grundy and Kabaila suggested that the systematic control of the forces in the props using torsion wrenches or some similar means could be used if economy in design justify such strict constructional control.

In addition to the above factors, the performance of concrete floors must be considered with respect to strength (flexure, shear and bond).

The development of flexural strength of reinforced concrete member for different ratios of tensile reinforcement with crushing strength of concrete was studied by Blakey and Beresford⁽³⁾. As shown in Figure 13 the change in flexural strength of the member for a large change in concrete compressive strength at any level of reinforcement is no more than 10%. Thus the loading at least up to design load at any stage, when the concrete has not reached its design strength will not imply any serious encroachment on the factor of safety against flexural failure.

The shear and bond strengths are functions of the square root of the compressive strength of concrete. So these

UNIVERSITY OF OTTAWA
LIBRARY
OTTAWA, CANADA

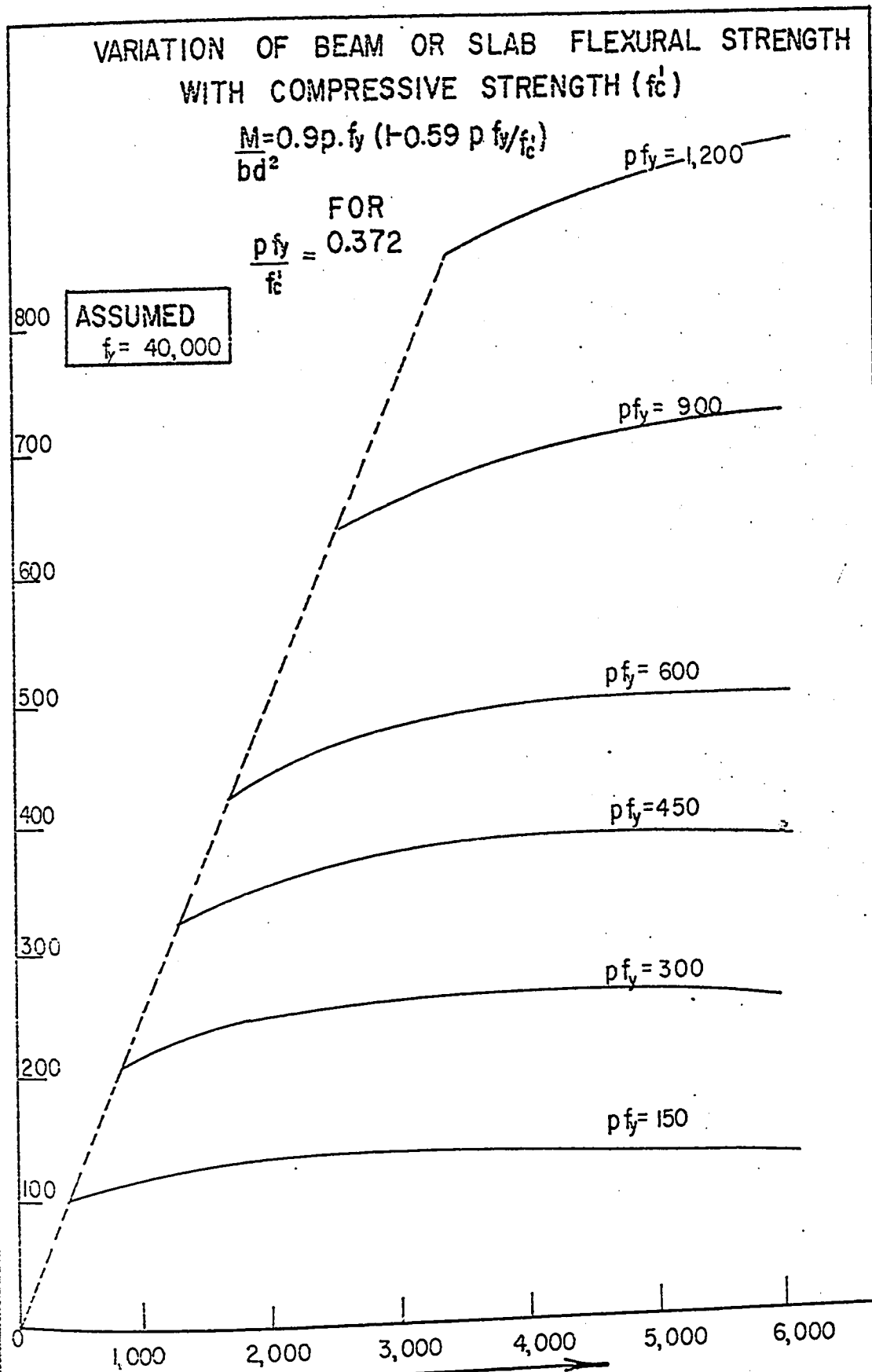


FIG. NO. 3 COMPRESSIVE STRENGTH (f_c') IN PSI. REF. NO. 3

strengths will not be very much affected with the wide variation of compressive strength. Beresford⁽²⁾ has stated that the influence of these factors on load analysis is not appreciable.

Thus the main object of this investigation was to determine the actual load ratios applied to slabs and shores during construction and to compare these with the theoretical ones and subsequently to determine a shoring schedule in practice for different rates of construction, type of cements and ambient temperatures, etc.

CHAPTER 4

FIELD INVESTIGATIONS

This chapter contains a brief description of the structures, which have been investigated and the experiments performed on them. As mentioned before, the object of this investigation was to determine the load ratios experienced by the shores and reshores during construction and thereby to find out the loads taken up by the floor-slabs at different ages during the construction period.

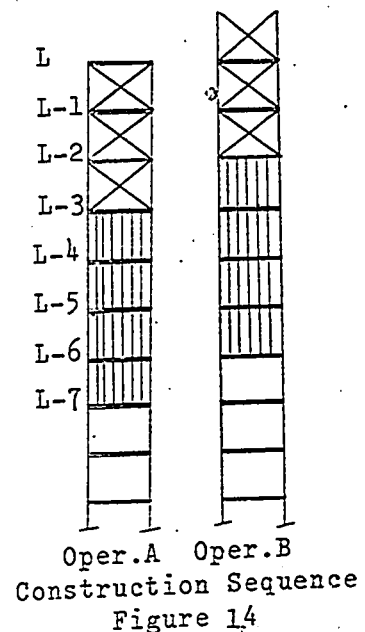
Description of Construction Sequence

In a typical construction cycle, as already mentioned, there are two alternating operations, which control the loads being applied to the slab.

These are:

- 1) Placing a fresh slab (Operation A)
- 2) Removing the lowest level of shores
(putting in reshores if needed)
(Operation B)

For example consider a typical construction rising at the rate of 2 floors per week and employing three levels of shores and say four levels of reshores. On the day that



the slab at level "L" is cast (Operation A), shores are in position under the slabs at level "L" (0 day old), "L-1" (say 3 days old), "L-2" (7 days) and reshores are in position under the slabs at level "L-3" (10 days), "L-4" (14 days), "L-5" (17 days), "L-6" (say 21 days), as shown in Figure 15. The load of eight slabs in the system plus the formwork will be distributed between the seven 'cured' slabs (slabs at level "L-1", "L-2", "L-7" in some manner which was to be determined experimentally.

After N days from the time the slab at level "L" is concreted, the shores along with the formwork under the slab at level "L-2" are removed and placed at higher level, whereas reshores are placed under the slab at level "L-2". Reshores under the slab at the lowest level ("L-6") are also removed (Operation B), see Figure 14 - Operation B. The forces formerly in the removed shores will be distributed between the slabs above it and the slabs below will be relieved, by the equivalent amount of force. The redistributed loads carried by shores and reshores will be measured.

The formwork which weighs about 10% of the slab it is supporting, is assumed in this analysis to be included in the self weight of the slab.

Apartment Building at Alta Vista Drive, Ottawa

This was the first structure to be investigated, which is a twenty-two storey high-rise apartment building on Alta

Vista Drive, Ottawa. (Figure 15). It is a flat-slab type building commonly used for apartments. The thickness of the slab is 8" and has the maximum panel length of 20' 6". The design details of a typical floor are shown in Appendix 6.

On this building three levels of shores and four levels of reshores were used. The construction rate was approximately two floors a week. At the time of starting the measurements on this building, six floors were already cast. Thus the experiments were performed from the 7th floor slab to the 13th floor slab to obtain data on the full construction cycle. Measurements were carried out during the period from July 24th to August 26th, 1971. The average temperatures during the period were between 55°F to 70°F. The variation of the atmospheric temperature and the rainfall during the period is shown in Figures 17 and 18.

On this building tubular steel flying scaffold frames were used for shoring purposes. The details of which are shown in Figure 18. For experimental purposes a typical floor area, resting on four reinforced concrete columns, as shown shaded in figure of Appendix 6 was chosen and the eight posts numbered as 1,2,3,....,8 were instrumented (see Figure 2.0). Since it is probable that the post will experience bending under loading, two electrical resistance foil-type strain gauges were affixed on opposite sides at each named post to avoid measuring bending stresses as shown in the Detail "D" of Figure 19.

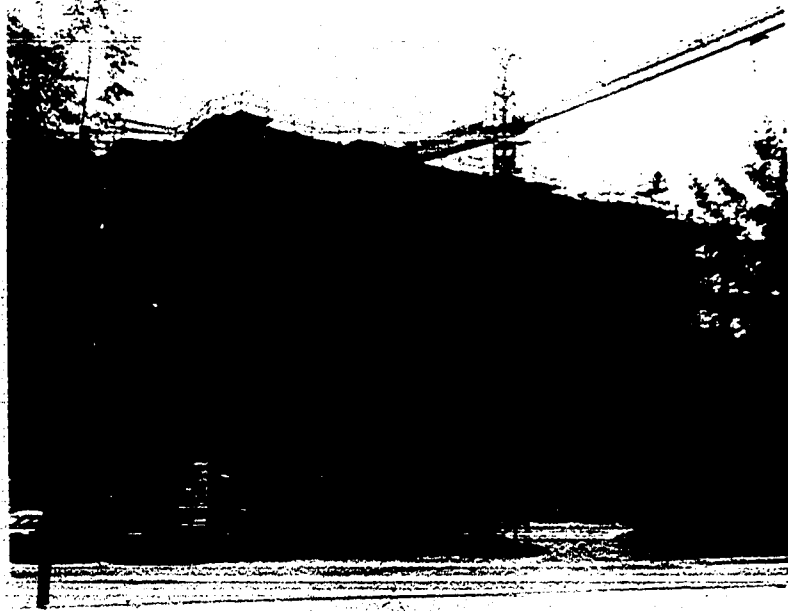
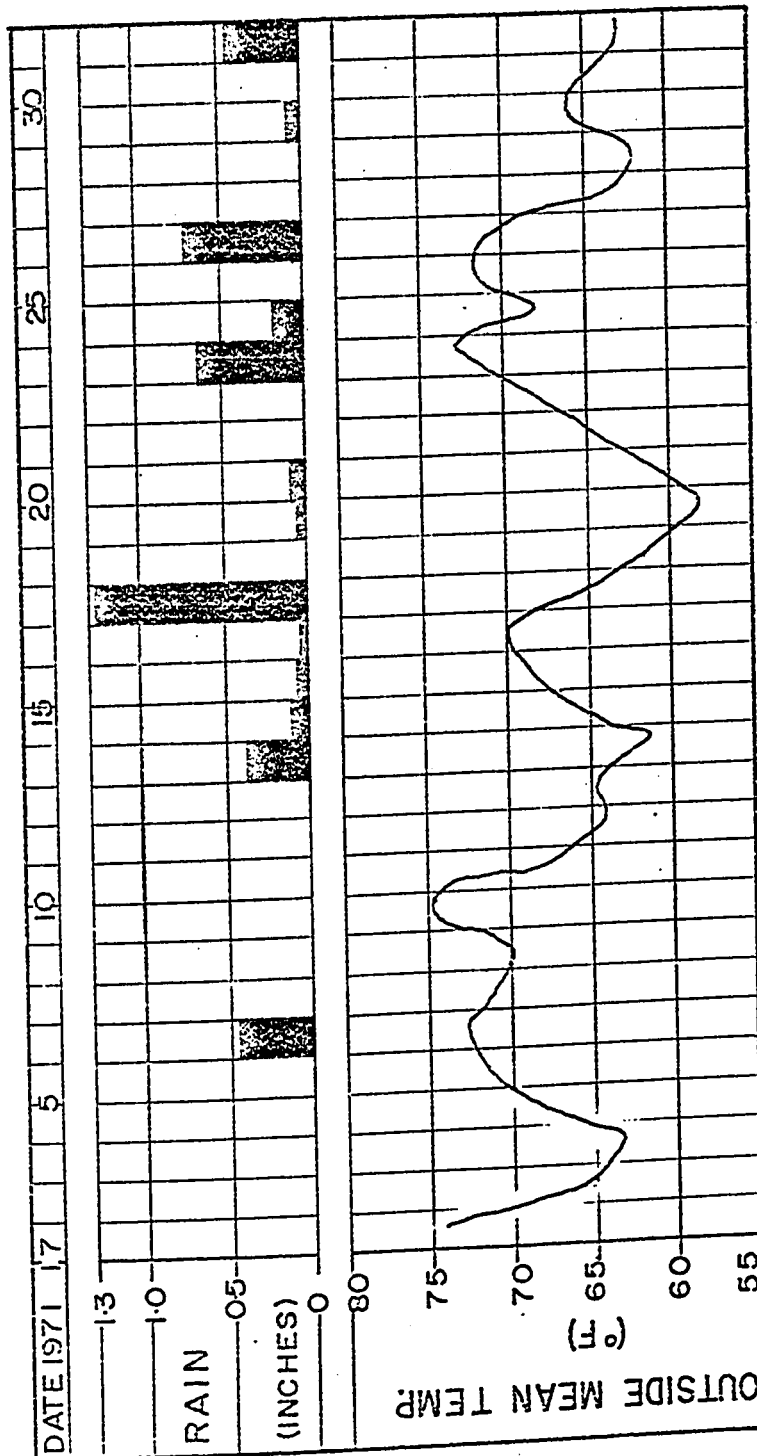


Figure 15. Photographs of the Apartment Building at
Alta Vista Drive, Ottawa



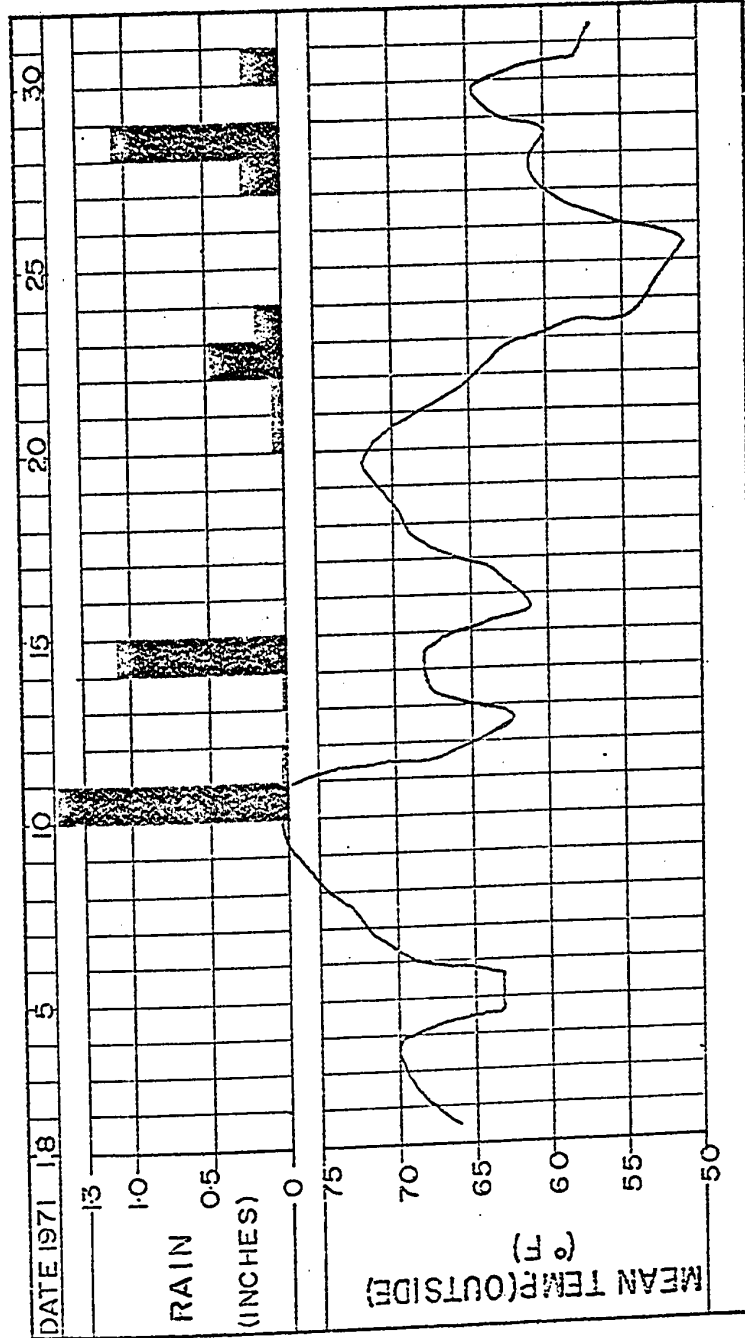
TOTAL = 4.39"

MAX. 85°F

MIN. 49°F

METEOROLOGICAL CONDITIONS DURING THE
MONTH OF JULY 1971

FIG. NO. 16



TOTAL = 4.87"

MAX. 93° F

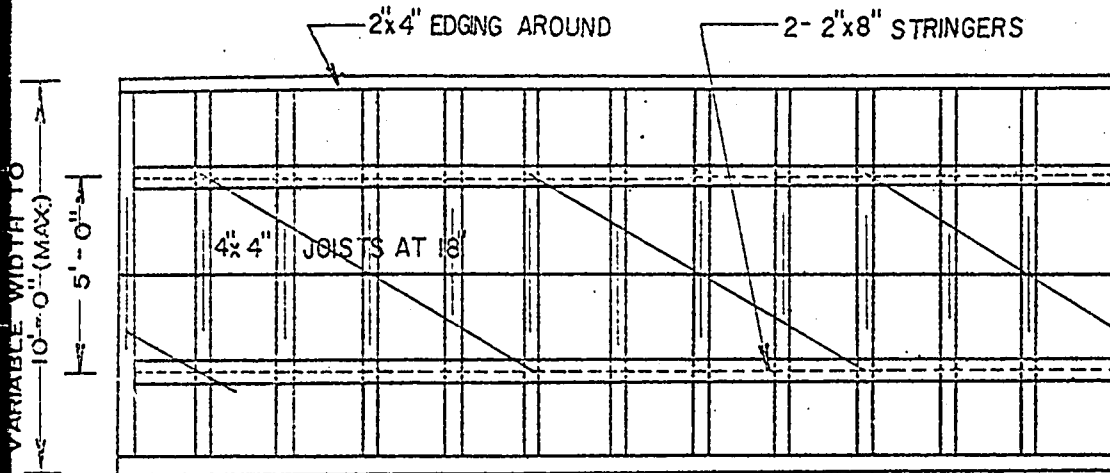
MIN. 41° F

METEOROLOGICAL CONDITIONS DURING THE

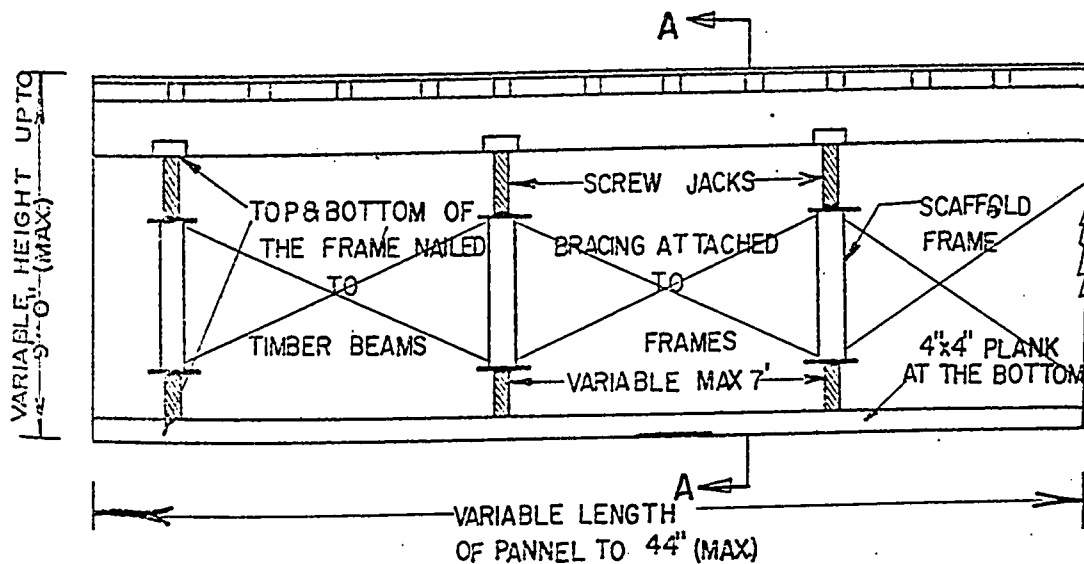
MONTH OF AUGUST 1971

FIG. NO.17

APARTMENT BUILDING AT ALTA-VISTA DRIVE, OTTAWA
TYPICAL FLYING FORM DETAILS



REFLECTED HORIZONTAL GRID LAYOUT

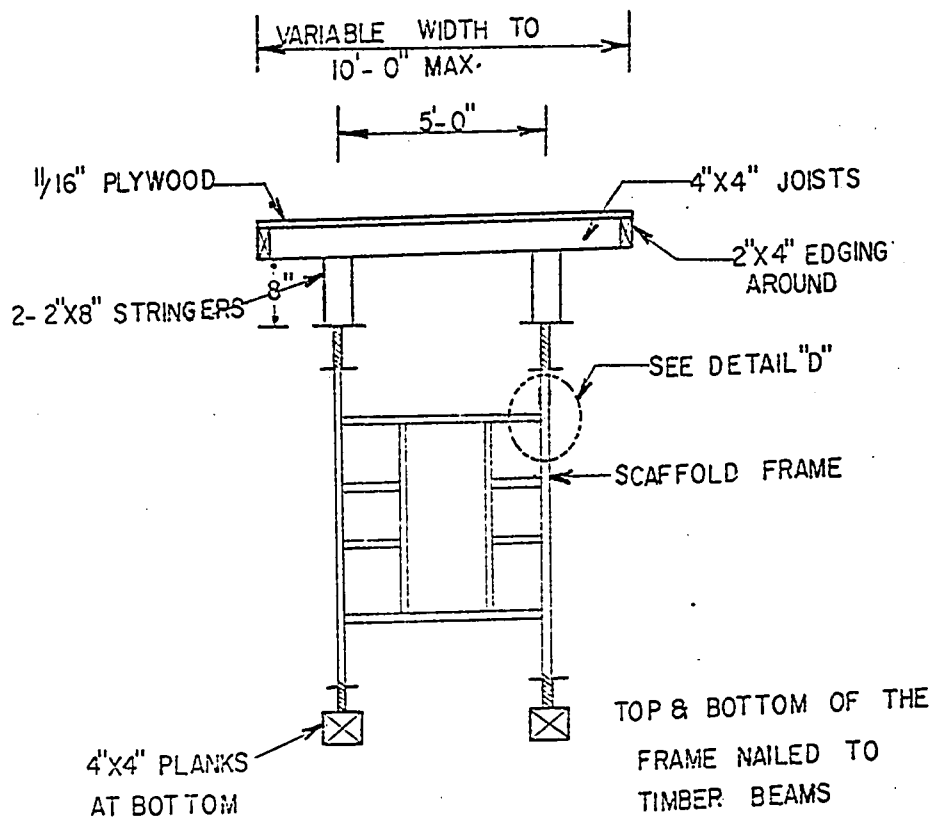


CROSS SECTION PARALLEL TO STRINGERS

FIG. NO.18

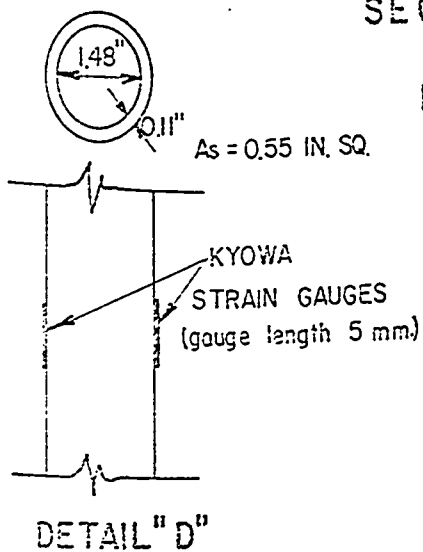
APARTMENT BUILDING AT ALTAVISTA DRIVE

SHORING UNIT DETAILS



SECTION A-A

FIG.NO.19



By recording the initial readings from the strain indicator before casting the slab and comparing it with the result after the upper floor-slab (slab at level 7) is concreted, the loading on each named post was measured and is listed in Figure 22 under operation A-7 (see Appendix 4).

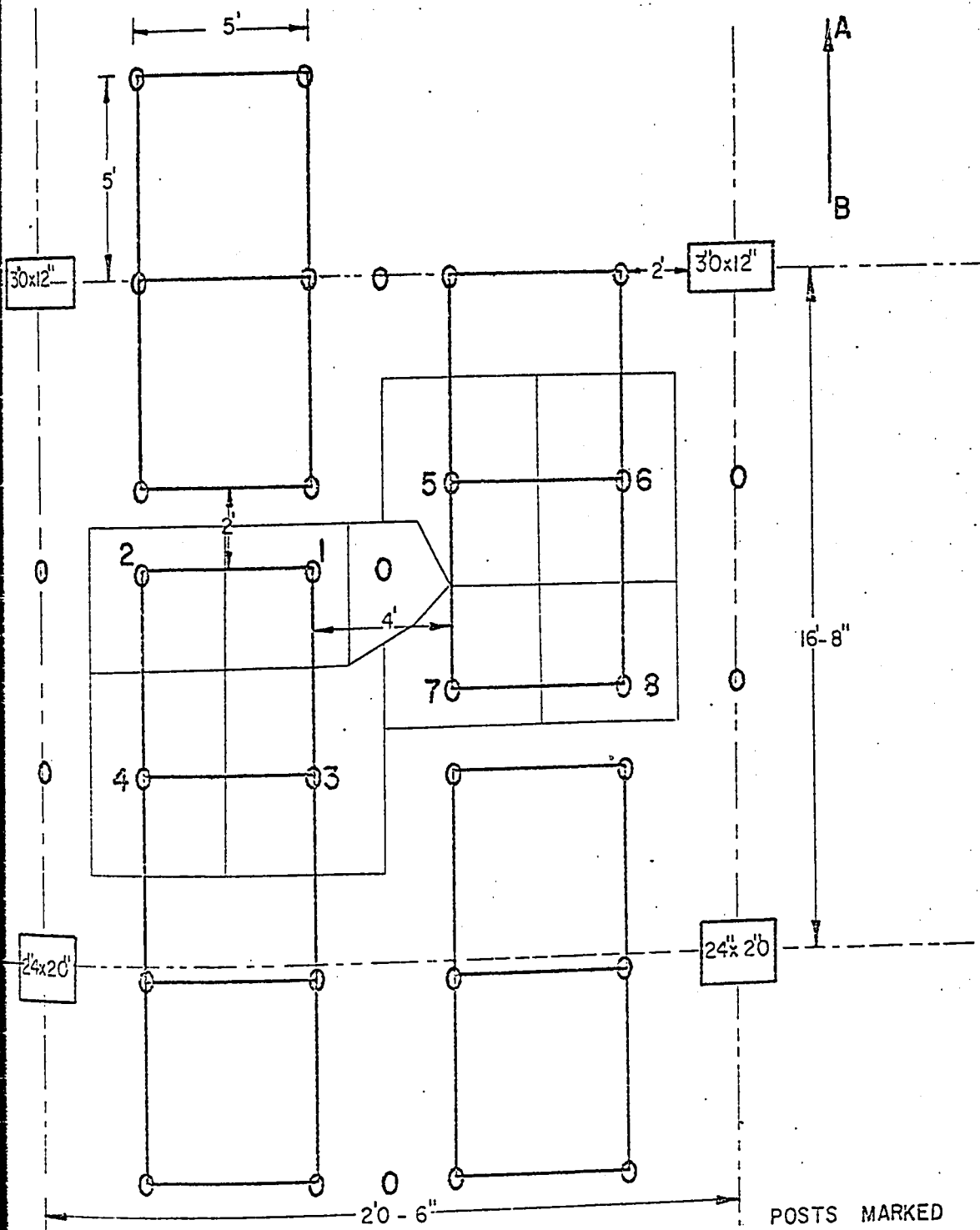
The floor area carried by each post, when the concrete was just poured was calculated by four different ways as shown in Appendix 3 and it was found that the most practical way of finding the theoretical loads on shores is to consider the weight of the concrete of the proportional area of the slab resting on that particular post. The loads carried by shores, reshores and slabs are expressed as a factor by which, the self weight of the slab plus formwork, must be multiplied. This factor is referred to as the 'load ratio'.

The second part of this investigation was to determine the load redistribution in the shores and reshores, when the formwork along with the posts from the lowest level of shores (under the slab at level 5) was removed and placed on a higher level, (over the slab at level 7) and reshores at the lowest level were also removed (Operation B). When this operation is performed, measurements were again taken on the shores under the slab at level 7 (as entered in Figure 22 under Operation B-5).

The eight posts, exactly in the same position as the previously instrumented posts under the slab at level 7, on level 8 were instrumented and initial zero readings taken.

UNIVERSITY OF
VANCOUVER
LIBRARY

APARTMENT BUILDING AT ALTA-VISTA DRIVE, OTTAWA

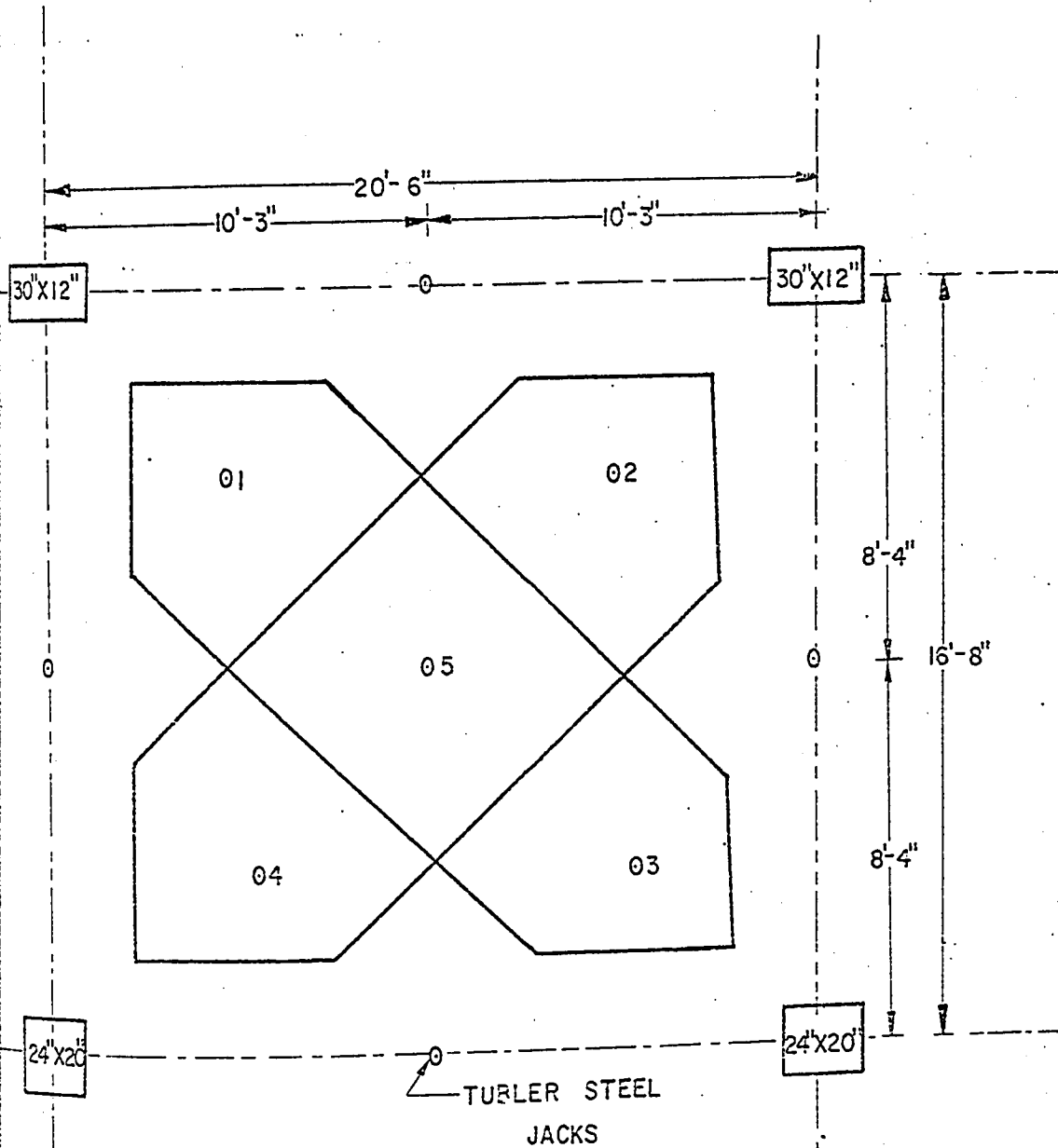


TYPICAL SCAFFOLD ARRANGEMENT
TO SUPPORT THE SLAB BETWEEN
FOUR COLUMNS

FIG. NO.20

POSTS MARKED
1, 2, 3.....8
ARE INSTRUMENTED

UNIVERSITY OF OTTAWA
VANIER LIBRARY



PTS MARKED

2.....5 ARE

INSTRUMENTED

TYPICAL RESHORING ARRANGMENT

APARTMENT BUILDING AT ALTA-VISTA

OTTAWA

FIG. NO.21

STEEL JACKS

I.D = 1.52"

DRIVE, $A_s = 1.04$ SQ.IN.

UNIVERSITY OF
VANIER LIBRARY

When the floor slab at level 8 was cast (Operation A), measurements for the loads carried by the posts under the slabs at levels 8 and 7 were recorded as per Figures 23 and 22 respectively under operation A-8.

In this way the posts under the new floor to be cast were instrumented and the loads on both the shores and reshores recorded, when the new slab was poured (Operation A) and when the lowest level of formwork, including the shores, was removed and placed on a higher level (Operation B). This process of recording the load after each Operation A and B was continued until the whole cycle was completed. The measurements are recorded in Figures 22 to 26 for shores and reshores under floor slabs at level 7 to level 13 respectively and are expressed as load ratio in the last column of each figure. (Figures 22 to 26 are to be found in Appendix 4).

Calculation of Load Ratios Carried by Floor Slabs

Referring to Figure 22, operation A-7, when the floor slab at level 7 was cast, the shores under the slab were carrying a load of 1.03 times the load of the slab plus formwork and the slab at level 7 (0 days old and behaving as a fluid) is carrying zero load.

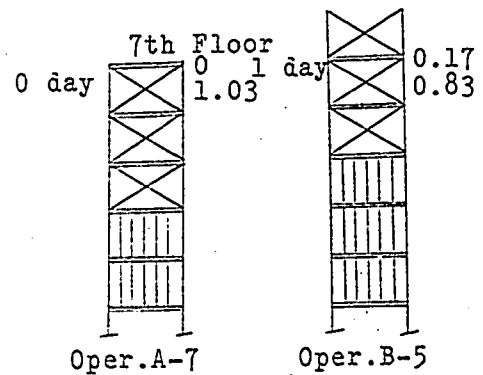
Now when the lowest level of shores (i.e. shores under the slab at level 5) are removed and placed on the higher level (Operation B) the measurements on the shores under the floor slab at level 7 showed that a load ratio of

UNIVERSITY OF
VANCOUVER
LIBRARY

0.83 (Figure 22 under operation B-5).

Obviously the slab at level 7 (which is now 1 day old) retained a load ratio of 0.17 ($1.00 - 0.83 = 0.17$) as shown in the adjoining Figure 27.

Again when the slab at level 8 was cast, readings on the shores under the slabs at levels 8 and 7 are 0.99 and 1.65 respectively as per Figures 23 and 22 under operation A-8. This means the load sustained by the slab at level 8 (0 days old) is zero and the slab at level 7 is 0.34 ($1.99 - 1.65 = 0.34$).



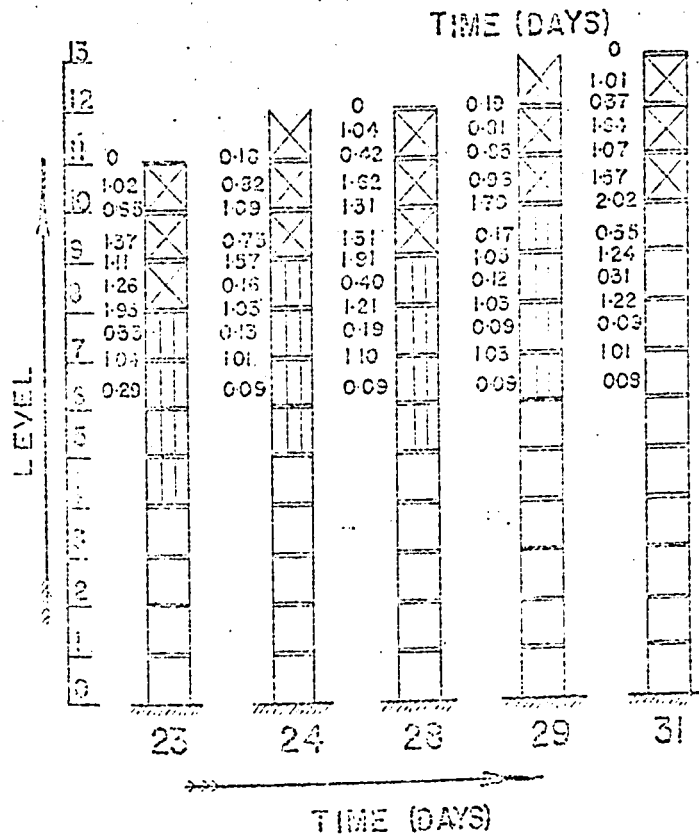
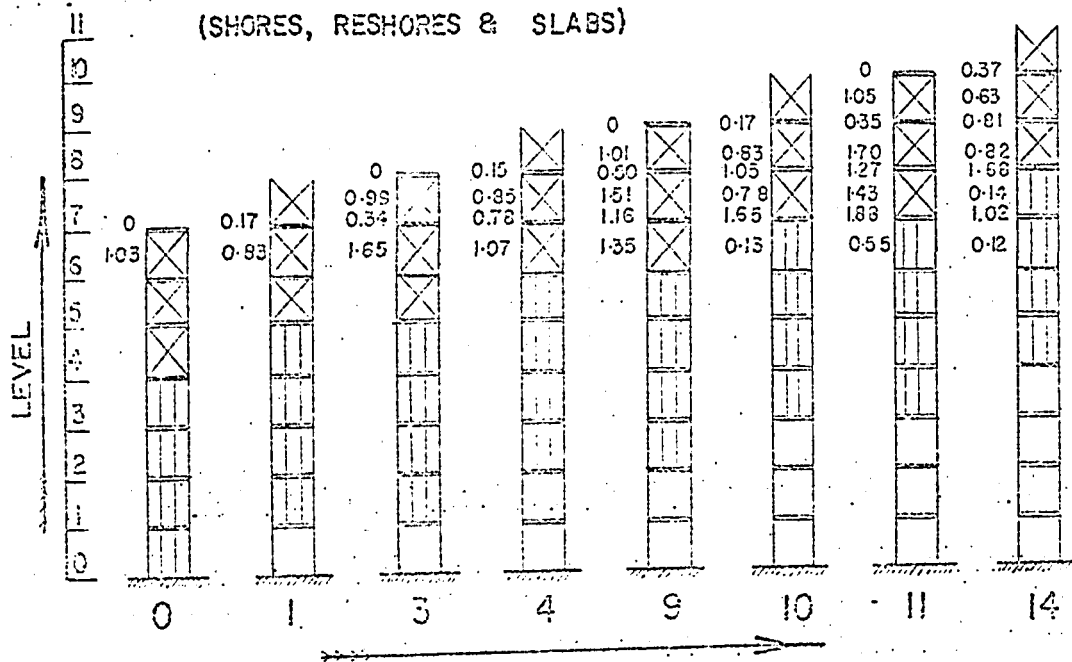
Calculation of Load Ratio Carried by a Floor

Figure 27

In this fashion the loads on the different floor slabs under Operations A and B were calculated at different ages as shown in Figure 28. The loads on different levels of shores, reshores and floor slabs under Operation A and B and at different ages were also calculated on the basis of the theory presented by Grundy and Kabaila with the exception that when the formwork along with the shores at the lowest level is removed, redistribution of the loads in the upper slabs will be as per their stiffness, but the lower slabs will be relieved and will be carrying their own weight only and thus the reshores will be carrying no loads at that time. But when a new slab at a higher level is cast, its weight will be shared by all the

LOAD RATIO APPLY TO ADJACENT COMPONENTS

(SHORES, RESHORES & SLABS)



EXPERIMENTS STARTED
WHEN
7TH FLOOR SLAB IS POURED

EXPERIMENTS CLOSED
WHEN
SLAB AT LEVEL 13 IS POURED

CONSTRUCTION LOADS ON SLABS WITH SHORED FORM-WORK
IN MULTISTORY APARTMENT BUILDING AT ALTA-VISTA DR.

(ANALYSIS BASED ON MEASUREMENTS AT SITE)

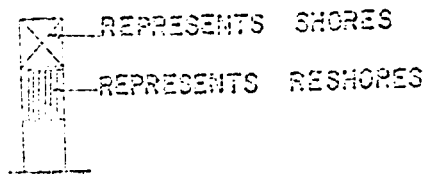
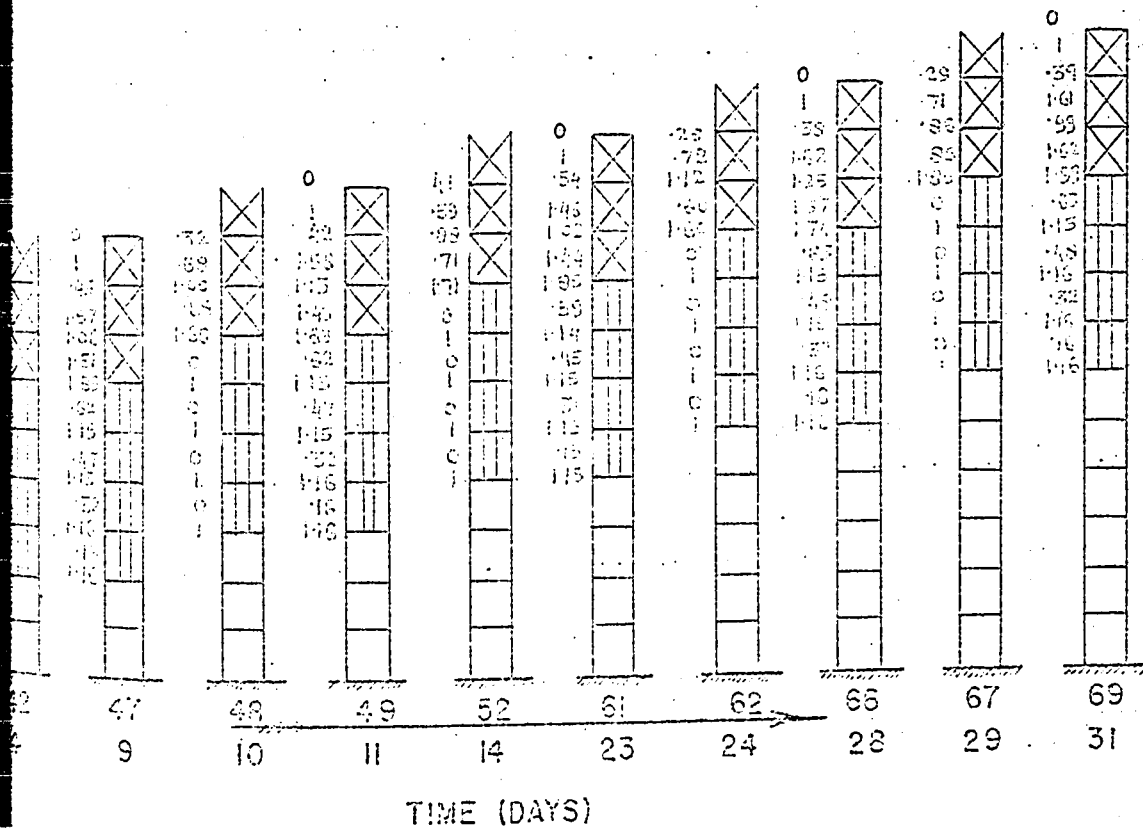
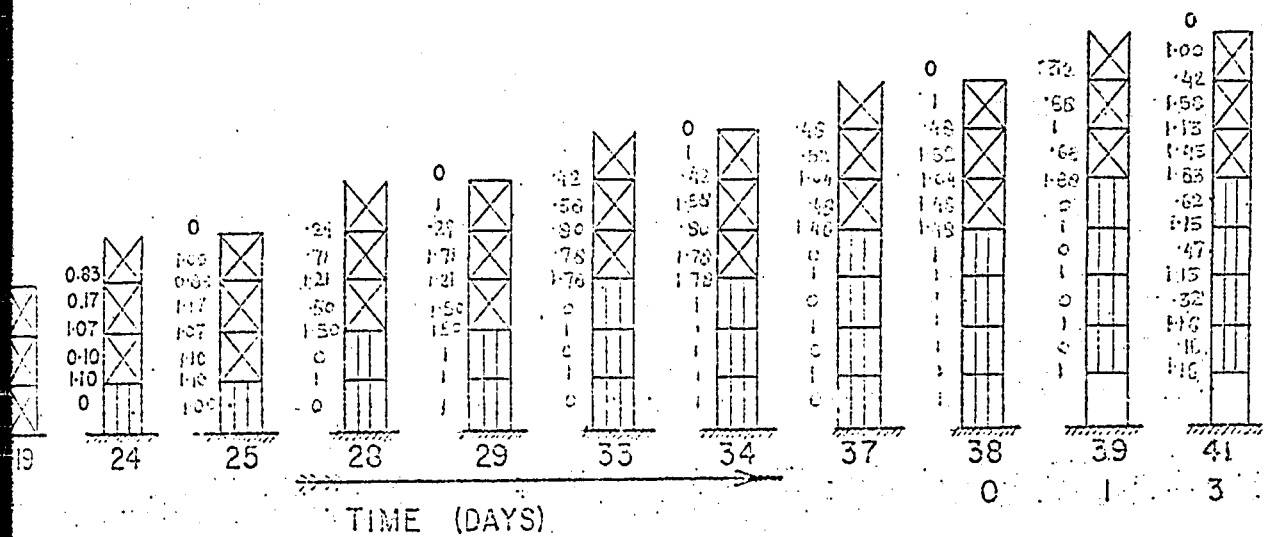


FIG. NO. 23



LOAD RATIO APPLY TO ADJACENT COMPONENTS
SHORES, RESHORES & SLABS
(THEORETICAL ANALYSIS, VARIABLE EQ)

APARTMENT BUILDING AT ALTA-VISTA DR. OTTAWA

FIG. NO. 29

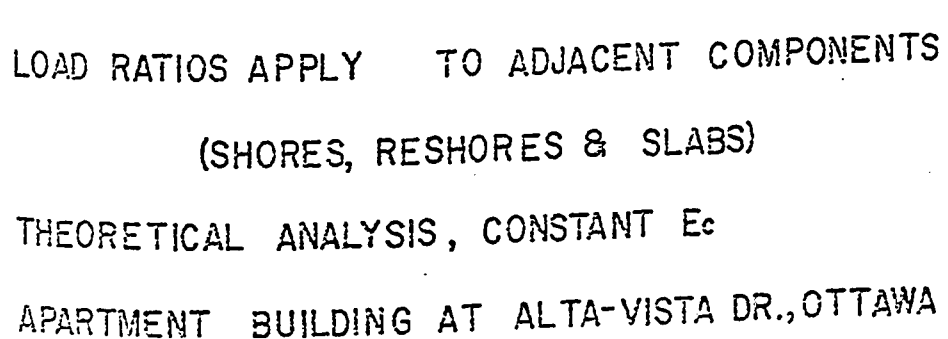


FIG. NO. 30

slabs (as per their stiffness) in the shores-reshores system. In this fashion the theoretical analysis proceeded as shown in Figures 29 and 30. A summary of the load ratios applied to adjacent components (shores, reshores and slabs), determined experimentally as well as theoretically, is given in Figure 31. These experimental and theoretical load ratios applied to adjacent components (shores, reshores and slabs) are plotted against time in Figures 32 to 43. These graphs show the experimental values (continuous lines) and the theoretical values (dashed lines). It is observed that the experimental results are in agreement with those predicted. The maximum load ratios carried by the slabs at different ages, determined experimentally and theoretically are as summarized below:

Slab at Level	Age (days)	Maximum Load Ratios	
		Experimental	Theoretical
7	11	1.88	1.83
8	20	1.93	1.85
9	19	1.91	1.74
10	20	2.02	1.99

The above figures show that the experimental values for maximum load ratios are quite close to that of theoretical values. It is also observed that the maximum load is always carried by the last slab under the shores, before those shores are removed. The most critical load ratio is 1.88 experienced by the slab at level 7, which is 11 days old. Thus the maximum load sustained during construction is 206.8 lbs/sq.ft at 11 days, effectively an overload of about 40%.

-50-
SUMMARY

STAGE/DAYS		FORM-7			8			9			10			11			12			13		
		AGE	SL	FO	AGE	SL	FO	AGE	SL	FO	AGE	SL	FO	AGE	SL	FO	AGE	SL	FO	AGE	SL	FO
7/0		0	0	103																		
		0	0	100																		
		0	0	100																		
8/1				017 093																		
		1	046	054																		
				032 090																		
9/3				054 065			0 099															
		3	060 149	0 0 100																		
				041 151			0 100															
10/4				078 107			015 035															
		4	100 064	1 04 035																		
				043 079			03 067															
11/9				115 135			050 151			0 101												
		9	119 132	6 05 145			0 0 100															
				100 151			04 157			0 100												
12/10				165 013			105 078			017 093												
		10	166 0	7 96 05			1 04 055															
				169 0			103 065			032 065												
13/11				185 055			127 143			035 170			0 103									
		11	172 055	0 11 120			2 05 142			0 0 100												
				183 062			113 141			0 4 156			0 100									
14/14				102 012			169 014			081 032			037 063									
		14	100 0	11 156 0			5 201 031			3 04 057												
				100 0			171 0			084 07			041 06									
15/23				104 029			163 033			111 126			065 137			0 107						
		23	114 044	20 170 055			14 115 129			12 05 142			0 0 100									
				114 045			165 055			102 141			051 145									

LOAD RATIOS APPLY TO ADJACENT COMPONENTS (SLABS,
SHORES & RESHORES)

(EXPERIMENTAL & THEORETICAL RESULTS)
APARTMENT BUILDING AT ALTA-VISTA DR, OTTAWA

FIG. NO. 31

CONTINUED ON NEXT PAGE

FIG. NO. 31

CONTINUED

STAGE/DAYS		FORM-7			8			9			10			11			12			13		
		AGE	SL	FO	AGE	SL	FO	AGE	SL	FO	AGE	SL	FO	AGE	SL	FO	AGE	SL	FO	AGE	SL	FO
15/24		104	009		103	013		157	016		109	073		018	082							
		24	100	0	21	100	0	15	153	0	13	100	055	1	04	055						
		100	0		100	0		100	0		112	060		020	077							
17/23		110	009		121	019		131	040		131	131		042	162		0	104				
		23	114	030	25	114	044	19	17	059	17	111	130	5	053	141	0	0	100			
		115	032		115	043		17	067		125	137		033	162		0	100				
18/29		103	009		103	009		03	012		179	017		085	095		019	081				
		29	100	0	26	100	0	20	100	0	18	152	0	6	100	055	1	043	057			
		100	0		100	0		100	0		185	0		031	069		029	071				
19/31		101	009		122	009		124	031		202	051		107	157		037	164		0	101	
		31	115	015	23	114	030	22	114	041	20	17	058	8	115	131	3	057	143	0	0	100
		116	016		116	032		115	043		19	033		100	161		03	161		0	100	

REPRESENTS SHORES

REPRESENTS RESHORES

Place du Portage, Hull, Quebec

This was the second building investigated, which again is a flat slab-type construction of 27 floors (see Figure 44). The thickness of the slab is 10" up to the 14th floor and from there upwards it is 8" thick. The maximum panel length is 25 feet. The design details of a typical floor are shown in Appendix 7. In the construction of this structure, three levels of shores were employed and the construction rate was about one floor a week. Eighteen floors were already cast, when the experimental work was started on this building and thus the experiments were carried out from the floor slab at level 19 to the floor slab at level 22 to complete the full construction cycle. The experiments were performed during the period September 5th to September 29th, 1971, during which the atmospheric temperature was ranging from 55°F to 70°F approximately. The variation of the atmospheric temperature and rainfall during the period in question is shown in Figure 45.

On this structure, adjustable tubular steel jacks were used for shoring purposes. The details of which are shown in Figure 46. Typical floor area as shown, shaded in the figure of Appendix 7 was selected for measurement purposes. Electrical strain gauges were affixed on nine posts in exactly

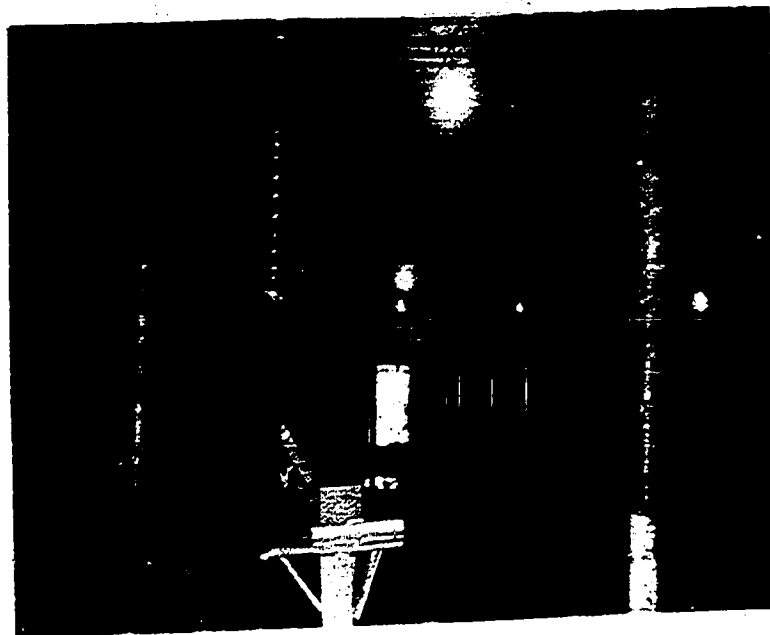
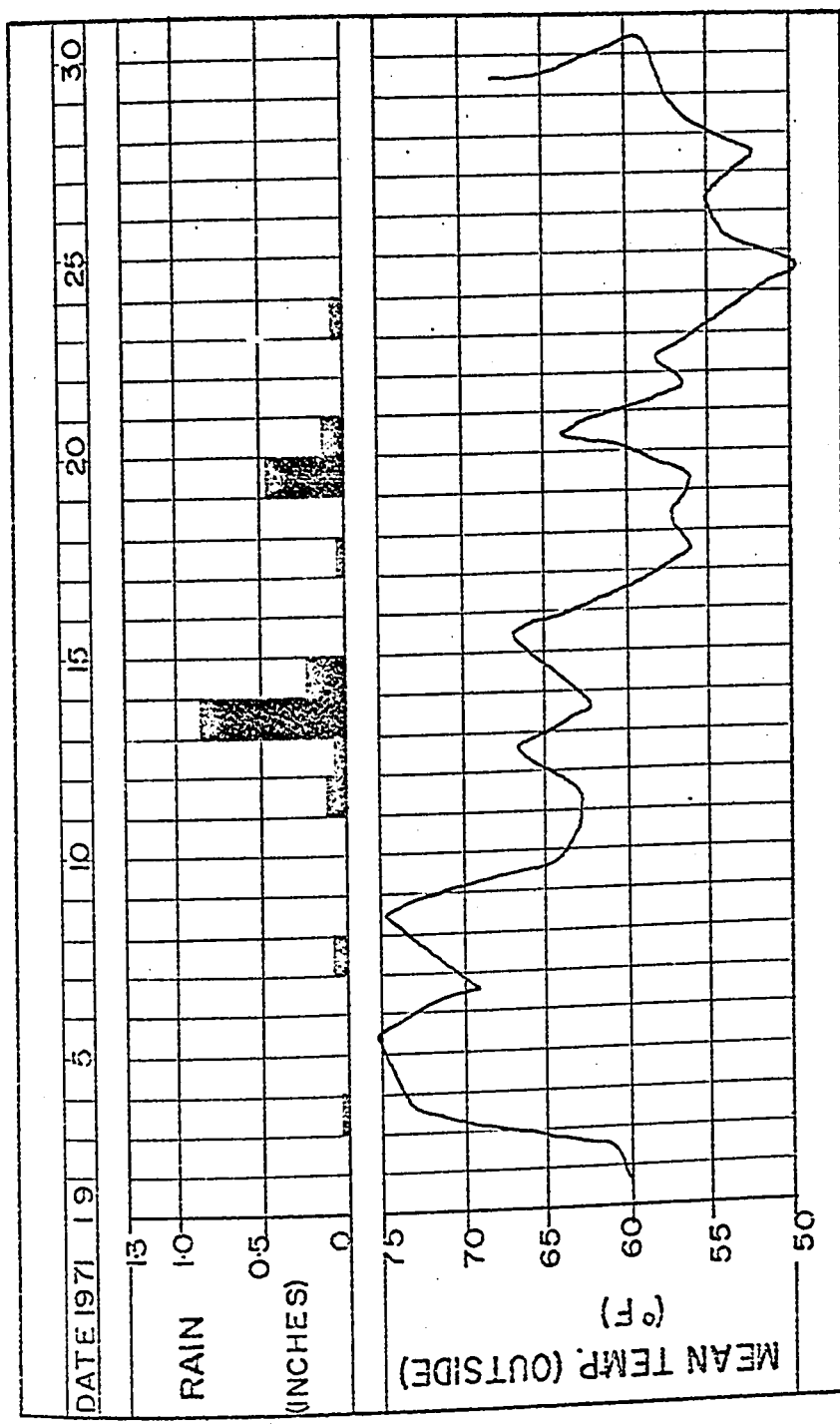


Figure 44 Photographs of "Place du Portage", Hull, Quebec.

TOTAL = 2.05"

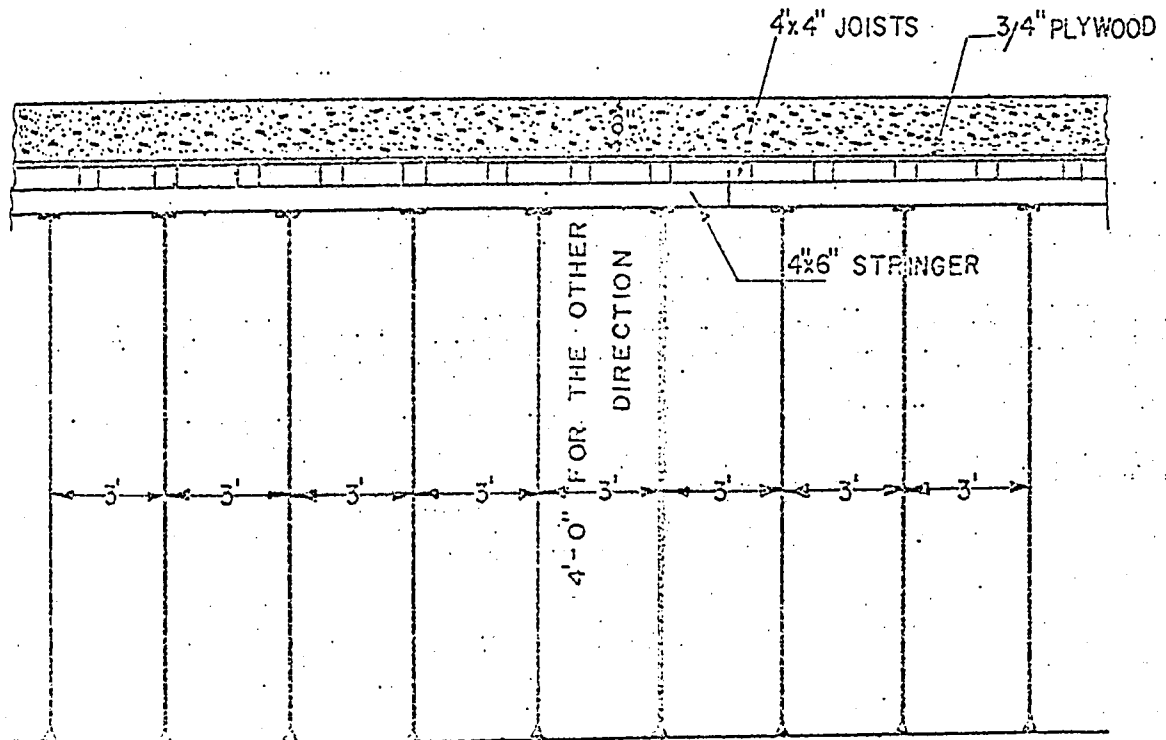
MAX. 85°F

MIN. 40°F



METEOROLOGICAL CONDITIONS DURING THE
MONTH OF SEPT 1971.

FIG. NO. 45



SECTION UNDER 8" THICK SLAB

TYPICAL SHORING ARRANGEMENT

PLACE DU PORTAGE, HULL

STEEL JACKS

O.D. = 1.91"

W.T. = 0.195"

I.D. = 1.52"

A = 1.04 SQ. IN.

FOR 1,000 LBS.:

$$\epsilon = \frac{1,000 \times 1}{10^4 \times 29 \times 10^6}$$

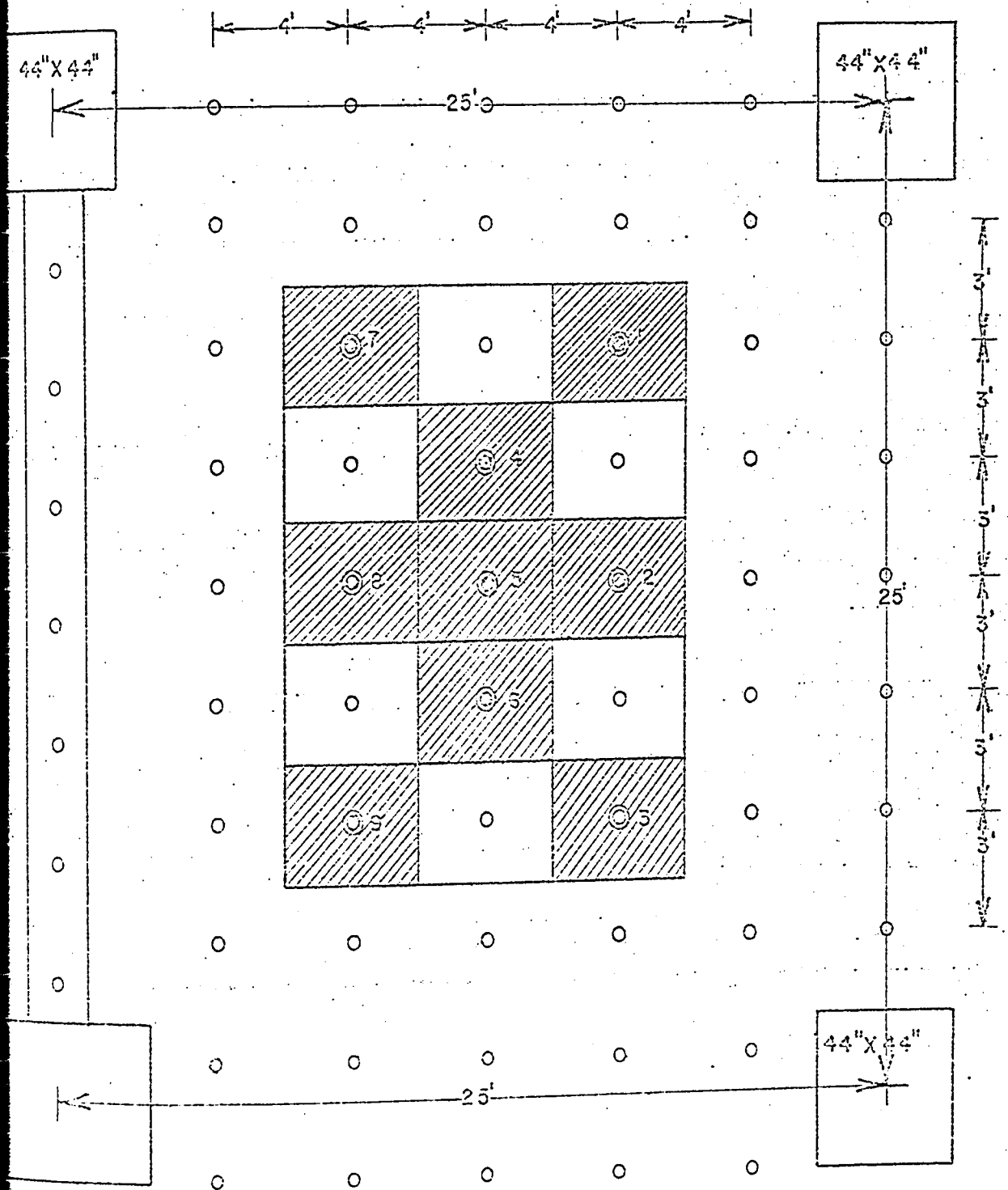
= 32.1 MICRO IN./IN.

FIG. NO. 46

the same fashion as for the previous structure. Load readings on posts 1 to 9 (see Figure 47) were recorded when the new floor slab (at level 19) was cast (Operation A) and was entered in Figure 48 under operation A-19. Measurements were repeated when the lowest level of the formwork along the shores (under floor slab at level 17) was removed and placed at a higher level (Operation B). These measurements are given in Appendix 4, Figure 48 under operation B-17. Operations A and B were continued until the full construction cycle was completed. The measured loads on the shores under floor slabs at levels 19 to 22 are shown in Figures 48 and 49 under Operations A and B. Hence the load ratios carried by the shores are completely known.

Calculations for the load ratios applied to the adjacent slabs were made exactly in the same fashion as for structure No. 1. The experimental and theoretical load ratios applied to adjacent components (shores and slabs) are shown in Figures 50 and 51, respectively. The experimental results are in close agreement with those predicted values (see Figure 52). The load ratios carried by the slabs and shores at different levels are plotted against time, see Figures 53 to 58 in App. 5.

The maximum load ratio, determined both experimentally and theoretically was 2.11 and was experienced by the 20-day old floor slab at level 19. Thus the maximum load sustained by the slab during construction is 232 lbs/sq.ft at 20 days, effectively an overload of about 32% on the assumed dead load and live load.

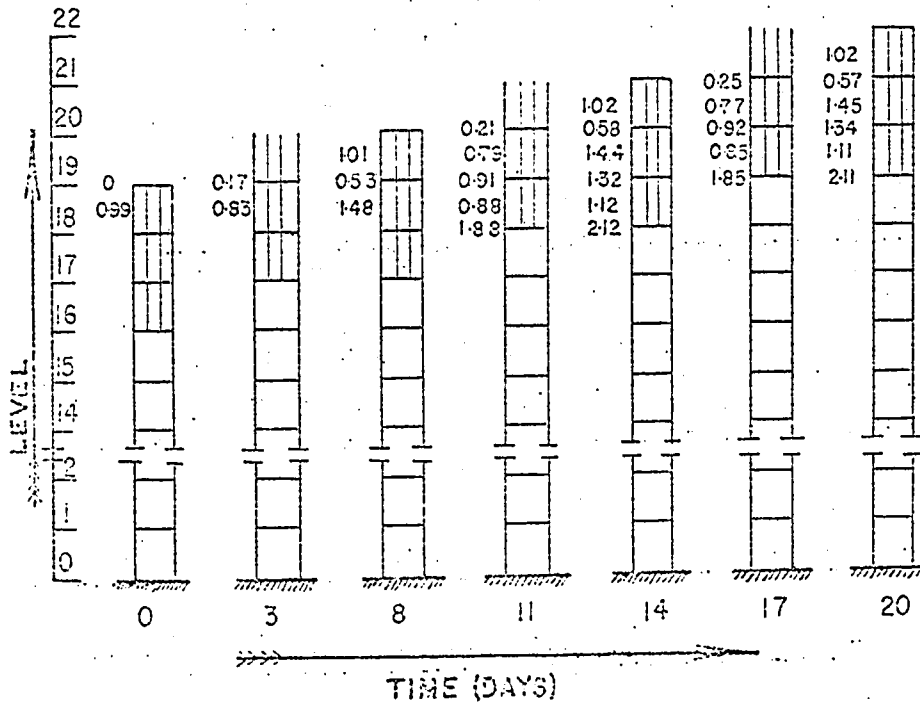


TYPICAL SHORING ARRANGEMENT
TO SUPPORT THE SLAB
PLACE DU PORTAGE, HULL

FIG. NO. 47

EXPERIMENTS STARTED WHEN SLAB AT LEVEL 19 IS CAST

EXPERIMENTS CLOSED WHEN SLAB AT LEVEL 22 IS CAST



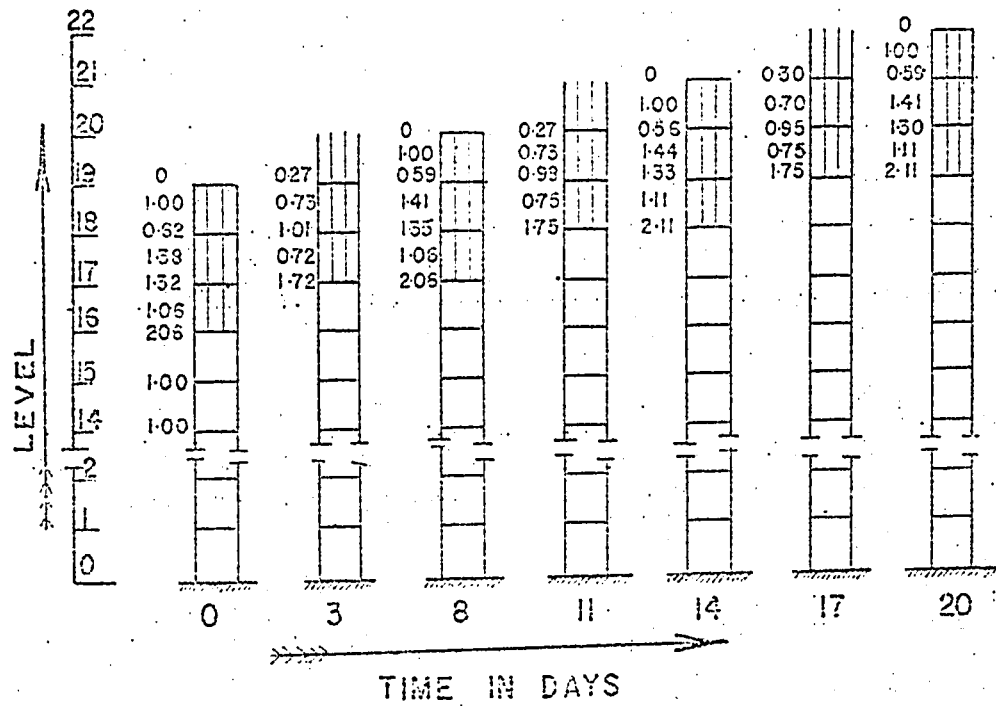
LOAD RATIOS APPLY TO ADJACENT COMPONENTS

(SHORES & SLABS)

ANALYSIS BASED ON MEASUREMENTS AT SITE

PLACE DU PORTAGE, HULL

FIG.NO.50



LOAD RATIOS APPLY TO ADJACENT COMPONENTS

SHORES & SLABS

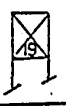
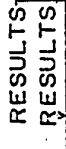
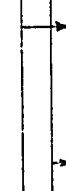
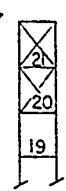
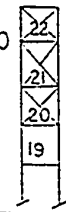
(THEORETICAL ANALYSIS, VARIABLE E_c)

(PLACE DU PORTAGE, HULL, QUEBEC)

FIG. NO.51

UNIVERSITY OF

-60-
SUMMARY

STAGE/DAYS		FORM → 19			20			21			22		
		AGE	SLAB	FORM	AGE	SLAB	FORM	AGE	SLAB	FORM	AGE	SLAB	FORM
19/0		0	0	0.99									
		0	0	1.00									
20/3		3	0.17	0.83									
			0.27	0.73									
21/8		8	0.53	1.48	0	0	1.01						
			0.59	1.41	0	0	1.00						
22/11		11	0.91	0.88	3	0.21	0.79						
			0.98	0.75		0.27	0.73						
23/14		14	1.32	1.12	6	0.58	1.44	0	1.02				
			1.33	1.11		0.56	1.44	0	1.00				
24/17		17	1.85	-	9	0.92	0.85	0.23	0.77				
			1.75	-		0.95	0.75	0.30	0.70				
25/20		20	2.11	-	12	1.34	1.11	0.57	1.45	0	1.02		
			2.11	-		1.30	1.11	0.59	1.41	0	1.00		

LOAD RATIOS APPLY TO ADJACENT COMPONENTS
(SHORES & SLABS)

(EXPERIMENTAL & THEORETICAL RESULTS)

FIG-NO-52 PLACE DU PORTAGE, HULL

The experimental analysis of the two structures discussed in this chapter indicates that the maximum load ratio lies between 1.88 to 2.11 and is carried by the last slab under the shores at the time of casting a fresh slab at the higher level.

Probable Accuracy of Experimental Results

The experimental values are likely to vary by about $\pm 10\%$ due to

1. The variation in atmospheric temperature between the dummy gauges and the active gauges.
2. Variation in the cross sectional area of different posts.
3. Large length (about 7'-8') of electrical connecting wires.
4. Plugging in and plugging out of the connecting wires several times during the measurements.
5. Differential effect of the wind, etc., on dummy strain gauge and on gauges affixed on posts.
6. Bond between the strain gauge and the steel post.

CHAPTER 5

RECOMMENDED PROCEDURE

Both the theoretical and experimental studies, described in this report show clearly that the reinforced concrete floor slabs in high-rise structures are subjected to heavy loads, during the construction period.

As mentioned in the Historical Review, Chapter 2, the load ratio in all the slabs connected by shores or re-shores increases when a fresh slab at a higher level is cast and the maximum load ratio is always carried by the last slab under the shores at that time. This was verified experimentally from the results of two high rise structures, one at Alta Vista Drive, Ottawa and the other at Hull, Quebec.

Design of Forms

As mentioned previously the Building Code requirement for reinforced concrete, ACI 318-71, Clause 9.3, p.26 that the required strength U provided to resist dead load D and live load L shall be at least equal to:

where
$$U = 1.4D + 1.7L^{(5)}$$

D = Dead load

L = Live load

In order to calculate shore and reshore requirements it is assumed that the design is adequate at 28 days. To allow for the variation in the slab strength with age it has been conservatively assumed to be proportional to cylinder strength. By reference to Figure 59 it can be seen to be conservative for all types of failure criteria.

The maximum load ratios obtained using the Grundy and Kabaila method with E_c constant are given in Figure 60 for various shore/reshore combinations. The detailed analysis for various shore/reshore combination is given in Appendix 6.

Shore requirements were calculated using the values in Figure 60 increased by 10% to allow for the error between measured and calculated results, 10% as the weight of the formwork and 20% as construction load factor.

In addition to all these factors, it is worthwhile to check the safety of the structure against shear failure.

The load carrying capacity during construction will depend on the ratio of the design live load (including the future partitions and finish loadings) to the dead load of the structural floor. Figure 61 was prepared to specify shoring and reshoring requirements during construction with respect to varying live load/dead load ratios, construction cycle and concrete strength.

In addition to the above criteria which is based on experimental experience for load carrying capacity of a floor slab, the following basic assumptions are adopted in preparing the above mentioned figure.

1. The weight and structural design of all the floors is substantially equal.

2. The weight of freshly placed concrete and the formwork is 110% of the floor load after the forms have been stripped. The construction load factor is assumed to be 1.2. Of course the construction factor should be greater than one. In ideal working conditions (e.g. summer construction) 1.2 may be reasonable, but a good agreement could be made to raise it to 1.4.

3. The placing and curing temperature of concrete during the early age of the floor is 70°F to 85°F.

4. The shores and reshores are evenly distributed throughout the floor and are sufficient at all levels.

5. Assumption regarding gain of concrete strength with age.

The use of Figure 61 can be illustrated by the following example:

Example

Suppose the construction rate is 7 days, L.L./D.L. ratio of 0.75, type I cement and three levels of shores. Now from the figure we get four levels of supports. If the 11th floor is formed and ready for concreting and the 9th floor has been stripped, then we should be having the shores under the 11th and 10th floors, whereas reshores under the 9th and 8th floors.

By observation of Figure 61, it can be seen that some slabs under low L.L./D.L. ratios are predicted to fail. Equally it is observed in practice that they do not fail. The calculated ultimate load is not necessarily a good

indication of the actual ultimate load. This apparent anomaly is because flat slabs are designed by the empirical method given in CSA, 1970 Clause 9.7⁽¹²⁾ or ACI 318-56, Clause 210⁽⁶⁾.

This empirical design method, assuming no gross detailing errors, contains an inherent conservatism estimated to be at least 1.4. This conservatism is due to the ultimate flexural moment being greater than that when the steel reaches yield; that a slab cannot collapse until a mechanism has formed and because the square yield criteria used to relate the failure of a slab under two orthogonal moments to a line moment is conservative. Provided flat slabs are always designed by this empirical procedure the design ultimate load could be increased. However, this is not good practice as any improvements in design method would eliminate totally or partially the implied extra 1.4 load factor.

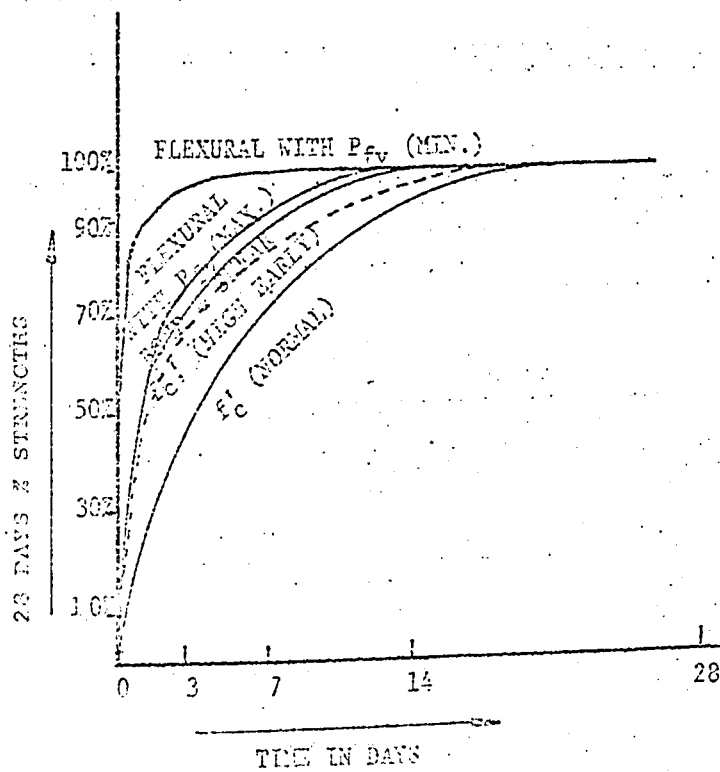


FIG. NO. 59 REF. NO. 61

THE ABOVE FIGURE CLEARLY SHOWS
 THAT BOND, SHEAR AND FLEXURAL STRENGTHS (BOTH FOR P_{fv} MAX. & MIN.)
 INCREASE FASTER WITH TIME THAN THAT OF COMPRESSIVE STRENGTH OF
 CONCRETE.

SUMMARY OF THEORETICAL AND CONSTRUCTION L.R. FOR VARIOUS SHORE/RESHORE COMBINATION, USING CONSTANT E_c

	NO. OF LEVEL OF RESHORES					TAYLOR'S METHOD
	0	1	2	3	4	5
THEORETICAL ABSOLUTE MAX. L.R./CONVERGED MAX. L.R						
1	-	$\frac{1.50}{1.50}$	$\frac{1.33}{1.33}$	$\frac{1.25}{1.25}$	$\frac{1.20}{1.20}$	$\frac{1.17}{1.17}$
2	$\frac{2.25}{2.00}$	$\frac{1.83}{1.77}$	$\frac{1.75}{1.67}$	$\frac{1.61}{1.60}$	$\frac{1.59}{1.55}$	$\frac{1.54}{1.52}$
3	$\frac{2.38}{2.00}$	$\frac{2.11}{1.87}$	$\frac{1.98}{1.83}$	$\frac{1.84}{1.76}$	$\frac{1.78}{1.72}$	$\frac{1.78}{1.72}$
4						
5						
CONSTRUCTION LOADS = (CONVERGED L.R.) X (1.10) (1.10) (1.20)						
1		2.18	1.93	1.82	1.74	1.70
2	2.90	2.57	2.42	2.32	2.25	2.20
3	2.90	2.72	2.66	2.56	2.50	2.50
4						
5						
CONCLUSIONS DERIVED						
1						
2						
3						
4						
5						

NUMBER OF LEVEL OF SHORES

FIGURE 60

- 1) Abs. max. and converged max. L.R., both increase by the increase of the number of level of shores. So number of level of shores should not be increased by 3, rather 2 level of shores are preferable, whereas number of level of reshores may be calculated for safe construction.
- 2) It is also clear that by increasing the number of level of reshores, both the L.R.'s decrease for same number of shores.
- 3) In any case maximum converged L.R. never exceed 2.

UNIVERSITY OF ALBANY

L.L./D.L.	0.50	0.75	1.00	1.25	1.50	1.75	2.00
ULTIMATE LOAD CARRYING CAPA- CITY OF FLOOR	2.25	2.67	3.10	3.52	3.95	4.37	4.80

REQUIRED NUMBER OF LEVELS OF SHORES AND RESHORES

CASTING RATE		(SHORES + RESHORES)						
14 DAYS	I	1+2	1+1	1+1	1+1	1+1	1+1	1+1
	III	1+2	1+1	1+1	1+1	1+1	1+1	1+1
7 DAYS	I	2+5	2+2	2+1	2+0	2+0	2+0	2+0
	III	2+5	2+1	2+0	2+0	2+0	2+0	2+0
3 DAYS	I	*	*	3+3	3+1	3+0	3+0	3+0
	III	*	2+5	3+1	3+0	3+0	3+0	3+0

RECOMMENDED SHORING AND RESHORING REQUIREMENT
(TEMP. 70°F to 85°F)

FIGURE 61

* For safe construction, must be designed for construction loads.

UNIVERSITY OF CALIFORNIA LIBRARY

The recommended procedure for required shoring and reshoring, which is given in Figure 61 can be modified to allow for the construction being carried out during low temperatures (say 55°F or 40°F). It is the rate of gain of concrete strength, which will be effected by the low temperatures.

Klieger⁽⁶¹⁾ studied the effect of mixing and curing temperature on concrete strength. Figure 62 shows the gain in concrete strength with time at different temperatures. This figure clearly indicates that for the first few days (say seven days or so), the rate of gain in concrete strength at low temperatures (say 55°F and 40°F) is appreciably slower than concrete which is mixed and cured at 73°F , but the difference is not so great at later ages (see Figures 63 and 64). Taking the rate of gain of compressive strength of concrete at 55°F and 40°F as given in Figure 62 and shown in Figures 63 and 64, Figure 65 was prepared to give the required shoring and reshoring during cold weather (55°F and 40°F) construction.

When the construction is carried out during very low temperatures (below 40°F), it is advisable that at the early age of each slab (say first seven days or so), it should be cured under artificial heating and Figure 65 can be employed to determine the number of propped floors during construction.

The analysis shown in Chapter 2 indicates that when three levels of shores are employed, the props on the ground

CEMENT ASTM TYPE	FABRIC- ATION & CURING TEMP. °F	COMPRESSIVE STRENGTH (PSI)				% OF 73° F (28 DAYS) STRENGTH			
		1	3	7	28	1	3	7	28
(NOR- MAL)	73	1410	3120	4490	6050	23.2	51.5	74.2	100
	55	580	1930	3750	6250	9.6	32.0	62.0	103
	40	80	730	2140	5180	1.3	12.1	35.4	85.6
(EARLY STRENGTH)	73	2640	3930	4780	5750	46.0	68.4	82.2	100
	55	1440	3180	4010	5470	25.0	55.4	69.6	95.2
	40	360	2000	4160	6260	6.3	34.8	72.4	109

COMPRESSIVE STRENGTH OF CONCRETE

AT LOW TEMPERATURES (55° & 40° F)

FIG. NO. 62

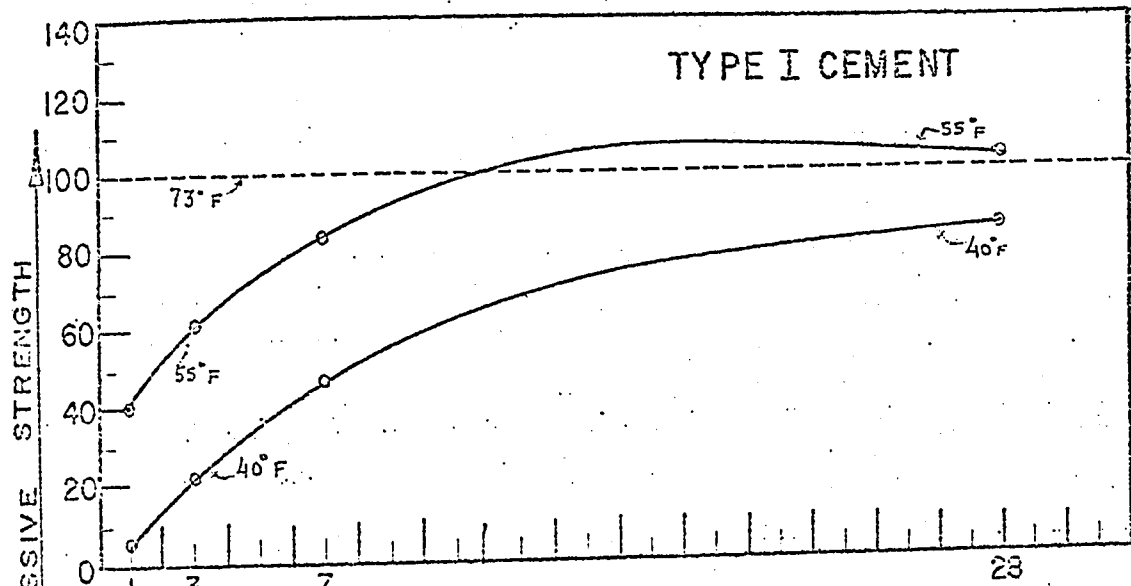
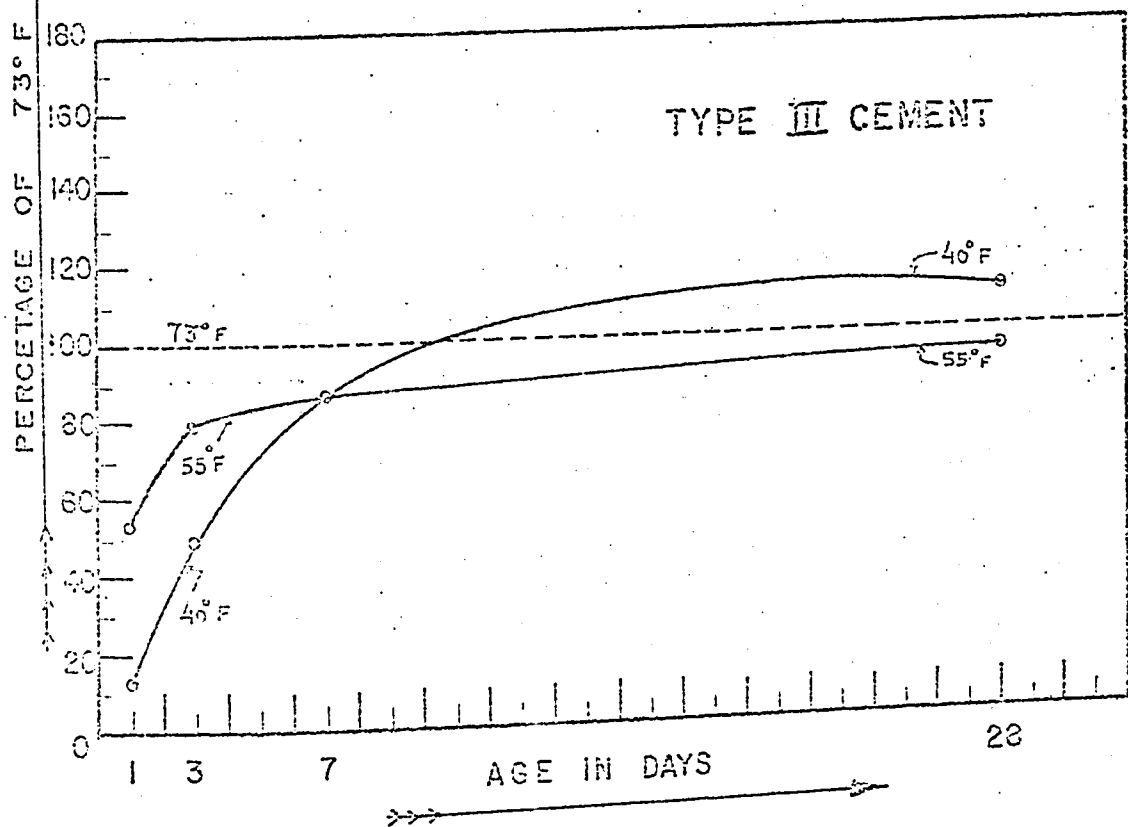


FIG. NO. 6



EFFECT OF LOW TEMPERATURES ON COMPRESSIVE
STRENGTH OF CONCRETE WITH DIFFERENT TYPE
OF CEMENTS

FIG. NO. 64

L.L./D.L.	0.50	0.75	1.00	1.25	1.50	1.75	2.00
ULTIMATE LOAD CARRYING CAPACITY	2.25	2.67	3.10	3.52	3.95	4.37	4.80

REQUIRED NUMBER OF LEVELS OF SHORES AND RESHORES

CASTING RATE

14	°F	I	1+2	1+1	1+1	1+1	1+1	1+1	1+1
DAYS	55	III	1+3	1+1	1+1	1+1	1+1	1+1	1+1
	40	I	*	1+4	1+2	1+1	1+1	1+1	1+1
		III	1+1	1+1	1+1	1+1	1+1	1+1	1+1
7	55	I	*	2+2	2+0	2+0	2+0	2+0	2+0
DAYS		III	*	2+4	2+1	2+0	2+0	2+0	2+0
	40	I	*	*	3+5	3+1	3+0	3+0	2+0
		III	2+4	2+1	2+0	2+0	2+0	2+0	2+0
3	55	I	*	*	3+5	3+1	3+0	2+2	2+1
DAYS		III	*	*	3+5	3+1	3+0	2+1	2+0
	40	I	*	*	*	*	*	*	*
		III	*	*	3+3	3+0	2+3	2+1	2+0

RECOMMENDED SHORING AND RESHORING REQUIREMENTS
(TEMP. 55°F AND 40°F)

FIGURE 65

* For safe construction, must be designed for construction loads, or provide the heating to have the placing and curing temperature 75°-85°F.

UNIVERSITY OF
VANUE LIBRARY

are carrying a load ratio of 3.00. Clearly it is necessary to see that the prop system at the ground floor should be adequate to carry this loading. The number of props can be reduced while reshoring the floor slab. It can easily be demonstrated that irrespective of the distribution of reshores the bending moment at the centre of the slab remains positive (sagging).

As mentioned in the Historical Review, Chapter 2, Taylor⁽⁶⁴⁾ using the technique of slackening and tightening the shores by rotating the threaded collars of the props, found the maximum load ratio was reduced to a greater extent. Thus taking the maximum load ratio during construction as obtained by Taylor, Figures 66 and 67 are prepared for recommended shoring and reshoring requirements.

It is clear from these figures that the number of propped floors is reduced compared to those given in Figures 61 and 65. But the results of Figures 66 and 67 can only be used in practice, provided the whole construction (especially at the time of slackening and tightening of the props) is performed under the strict supervision of experienced foremen or engineer.

L.L./D.L.		0.50	0.75	1.00	1.25	1.50	1.75	2.00
ULTIMATE LOAD CARRYING CAPACITY		2.25	2.67	3.10	3.52	3.95	4.37	4.80
REQUIRED LEVEL OF SHORES								
CASTING RATE								
14 DAYS	I	2	2	2	2	2	2	2
	III	2	2	2	2	2	2	2
7 DAYS	I	3	2	2	2	2	2	2
	III	2	2	2	2	2	2	2
3 DAYS	I	4	3	3	2	2	2	2
	III	3	3	2	2	2	2	2

RECOMMENDED SHORING REQUIREMENT
(TEMP. 70°F to 85°F)

FIGURE 66

- 1) To make use of the above table, Taylor's technique of slackening and tightening the shores must be employed.

UNIVERSITY OF
VANIER LIBRARY

L.L./D.L.	0.50	0.75	1.00	1.25	1.50	1.75	2.00
ULTIMATE LOAD CARRYING CAPACITY	2.25	2.67	3.10	3.52	3.95	4.37	4.80

REQUIRED NUMBER OF LEVEL OF SHORES

CASTING RATE

14 DAYS	55	I	2	2	2	2	2	2	2
		III	3	2	2	2	2	2	2
40		I	3	3	2	2	2	2	2
		III	2	2	2	2	2	2	2
7 DAYS	55	I	3	2	2	2	2	2	2
		III	3	2	2	2	2	2	2
40		I	4	3	3	2	2	2	2
		III	2	2	2	2	2	2	2
3 DAYS	55	I	4	3	3	3	2	2	2
		III	4	3	3	2	2	2	2
40		I	6	5	4	4	4	4	3
		III	4	3	3	3	2	2	2

RECOMMENDED SHORING REQUIREMENTS

(TEMP. 55°F and 40°F)

FIGURE 67

To make use of the above table, Taylor's technique of slackening and tightening the shores must be employed.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS

CONCLUSIONS

1. Investigations on the systems where a freshly placed flat slab floor is wholly supported on a number of previously placed floors through props clearly indicate that the construction-loads on the slabs exceed the design loads by a considerable margin and thus should not be ignored during the design of the slabs. Analytical determination of such loads, as carried out in this report predict the construction loads with acceptable accuracy and do not present any difficulty.

2. It is shown that increasing the number of levels of shores does not reduce the maximum construction load on the slab, rather the absolute maximum load increases with an increasing number of levels of shores. However, the age of the slab at which these maxima occur also increases, but the increase in concrete strength does not necessarily offset the extra load. Thus it is suggested that only two or three levels of shores should be used at the most.

3. It is observed that the absolute maximum load ratio depends upon the number of levels of shores employed. Thus slabs at levels 2 or 3 will be carrying the absolute maximum

UNIVERSITY OF
VANUE LIBRARY

load ratio depending upon whether the number of levels of shores used is 2 or 3 respectively, so it is suggested that the slab carrying the absolute maximum load ratio should be kept on props continuous to the ground level for a longer period.

4. As pointed out by Beresford (see Figure 8, Chapter 2) that after the solutions have converged, increasing the number of propped floors will not affect the load ratio sustained by the lowest slab in the system, as a converged load ratio of 2.00 is determined in each case after placing a fresh slab. However, the age of this slab will be greater as more propped floors are added to the system and thus the benefit of increasing the number of propped floors is thus derived from the application of the same highest load ratio (2.00) at a later stage.

5. If the lowest level of shores is removed before the reshores are installed the maximum load ratio on the lowest slab is reduced and the loads on the other slabs increased by a corresponding amount. Thus it is advantageous to place the reshores with only a light compressive force just to hold them in place. After pouring a new slab at a higher level, the force in the reshores will increase automatically.

6. It is clear from Figure 65, Chapter 5, that high early strength cement is not advantageous when the construction is carried out at 55°F. It can be used with advantage only when the temperature during construction is 40°F or below.

UNIVERSITY OF
VANIER LIBRARY

SUGGESTIONS

1. From the point of view of high construction loads, the use of light weight concrete slabs (and possibly prestressed flat plates) is suggested, so the dead load/total load ratio (and hence construction loads) will be reduced.

2. If cracking of the floor occurs during construction, which definitely indicates unsatisfactory performance of the slab under loads, it is advisable to slacken off the shores above the slab with only a light compressive force in them to hold them in place or one by one to slacken and lighten each of the shores above the floor which will reduce the loads on the slab beneath and will increase the loads by a corresponding amount on the slabs above.

3. If Figures 66 and 67 are used to determine the number of propped floors, the entire construction should be under the strict and constant supervision by skilled foremen, architects or engineers.

The method of analysis and procedures given in this report may be used conveniently in the design and construction of multistorey flat-slab structures, to obtain a quantitative estimate of the loads imposed on the structure during construction and rapid determination of the required number of propped floors.

LIST OF REFERENCES

1. Beamsville Express, Ontario, October 5, 1966.
"Wall Bracing Might Have Spared Life of Carpenter".
2. Beresford, F. D.
"An Analytical Examination of Propped Floors in Multi-storey Flat Plate Construction".
Construction Review, Vol. 37, November 1964, pp.16-20.
3. Blakey, F. A. and Beresford, F. D.
"Stripping of Formwork for Concrete in Buildings in Relation to Structural Design".
The Institution of Civil Engineers, Australia, Civil Engineering Transactions, C.E. T-4, pp.92-95.
4. Blakey, F. A.
"The Deflection of Flat Plate Structures".
Civil Engineering and Public Works Review, Vol. 58, September 1963, pp.1133-1136.
5. Building Code Requirement for Reinforced Concrete.
ACI 318-71, Clause 9.3, p.26.
6. Building Code Requirement for Reinforced Concrete.
ACI 318-63, June 1963, Clause 2104, pp.90-93.
7. Calgary Alberta, Alberta, December 21, 1971.
"Roof And The Walls Came Tumbling Down".
8. Calgary Herald, Alberta, November 9, 1971.
"Roof Collapses".
9. Calgary Herald, Alberta, October 20, 1964.
"Six Recovering From Injuries After Church Roof Collapses".
10. Charlottetown Patriot, P.E.I., June 12, 1964.
"Construction Mishap".
11. Chatham News, Ontario, May 26, 1970.
"Tons of Concrete Give Way".
12. Code For The Design Of Plain or Reinforced Concrete Structures.
CSA Standard A23.3-1970, Clause 9.7, pp.80-82.
13. Construction West Vancouver, B.C., May 26, 1969.
"Ill-Fated North Star Inn on Winnipeg's Portage Avenue."

14. Daily Star, Toronto, Ontario, December 17, 1965.
"Tangled Graveyard For Workmen".
15. Edmonton Journal, Alberta, November 9, 1971.
"Plant Floor Collapse Kills 5".
16. Edmonton Journal, Alberta, January 4, 1967.
"Lack of Qualified Engineering Blamed In Reservoir
Roof Fall".
17. Etobicoke Guardian, Islington, Ontario, April 22, 1971.
"Parking Garage Collapses".
18. ENR, April 29, 1971, p.11.
"Concrete Overpass Stringers Fall On Railroad".
19. ENR, April 1, 1971, p.15.
"Overpass Collapsed As Workmen Place Concrete".
20. ENR, March 25, 1971, p.14.
"Portion of Garage Collapses During Concrete
Placement".
21. ENR, February 4, 1971, p.13.
"Cause of Fatal Collapse Unknown".
22. ENR, August 20, 1970, p.22.
"Overpass Collapse Blamed on Falsework System".
23. ENR, June 11, 1970, p.9.
"Cantilever Box Girder Bridge Collapses During
Construction".
24. ENR, February 26, 1970, p.13.
"Roof Collapse Blamed On Unshored Composite Decking".
25. ENR, September 18, 1969, p.83.
"Nevada Overpass Collapse".
26. ENR, August 7, 1969, p.37.
"Balcony Fails During Construction".
27. ENR, March 6, 1969, p.13.
"Shores Collapse On Hospital Project".
28. ENR, June 27, 1968, p.7.
"Not Enough Bracing".
29. ENR, June 13, 1968, p.25.
"Concrete Pour Collapses Form".
30. ENR, May 2, 1968, p.31.
"Excavation Cave-In Buries Three".

31. ENR, May 2, 1968, p.31.
"Collapse Kills Bridge Builder".
32. ENR, January 11, 1968, p.31.
"Collapse Blamed on Supports".
33. ENR, December 14, 1967, p.27.
"Secrecy Veils Bridge Collapse".
34. ENR, May 18, 1967, p.33.
"Formwork Collapses After Pour".
35. ENR, May 19, 1966, pp.30-31.
"Collapses, Failures Take Heavy Toll".
36. ENR, August 1, 1963.
"Was Collapsed Wall Too Long?".
37. Globe and Mail, Toronto, Ontario, April 17, 1968.
"Three Die As Bridge Under Construction Collapses".
38. Globe and Mail, Toronto, Ontario, October 22, 1966.
"1 Dead, 9 Hurt In Collapse of Civic Centre".
39. Globe and Mail, Toronto, Ontario, October 22, 1966.
"Roof Falls in Alberta".
40. Globe and Mail, Toronto, Ontario, August 6, 1964.
"Roof Collapses Four Men Hurt".
41. Globe and Mail, Toronto, Ontario, December 7, 1963.
"Rink Collapse Kills Farmer, 5 Others Hurt".
42. Globe and Mail, Toronto, Ontario, February 7, 1963.
"2 Floors Fall, 20 Men Escape London Project".
43. Grand Prairie Herald Tribune, Alberta, September 17, 1964.
"Tower Crashes".
44. Grundy, P. and Kabaila, A.
"Construction Loads on Slabs with Shored Formwork
in Multi-Storey Buildings".
Journal of ACI, December 1963, pp.1729-1738.
45. Guelph Mercury, Ontario, June 2, 1964.
"Bridge Collapses Three Men Hurt".
46. Heavy Construction News, Toronto, Ontario, December 16, 1966.
"Clear Concrete Firm Off Collapse Charges".

47. Ho, Ka-Cheung.
"Preliminary Investigation Into Shoring System".
University of Ottawa, Department of Civil Engineering,
Ottawa, Canada, September 1970.
48. Kitimat Northern Sentinel, B. C., January 25, 1967.
"Bridge Stringer On Columbia Street Rots and Falls".
49. London Evening Free Press, Ontario, December 31, 1970.
"Roof Mishap Cause Still Unknown".
50. London Evening Free Press, London, Ontario, Sept. 14, 1966.
"Labor Department Probes Fatal Collapse of New Roof".
51. M. K. Hurd.
"Formwork For Concrete".
Special Publication No. 4, American Concrete Institute,
Detroit, p.5.
52. Montreal Star, Quebec, July 9, 1971.
"Overpass Collapse Injures 18".
53. Montreal Gazette, Quebec, May 26, 1970.
"Tons of Concrete Give Way".
54. Nielsen, K. E. C.
"Loads On Reinforced Concrete Floor Slabs and Their
Deflections During Construction".
Swedish Cement and Concrete Research Institute at the
Royal Institute of Technology, Stockholm, 1952.
55. Ottawa Journal, Ottawa, Ontario, June 25, 1968.
"Gloucester Probes Roof Collapse".
56. Ottawa Citizen, Ottawa, Ontario, August 13, 1966.
"Horror at Heron Bridge".
57. Ottawa Journal, Ottawa, Ontario, October 26, 1966.
"Elgin Street Building Collapse Trial".
58. Ottawa Citizen, Ottawa, Ontario, April 5, 1966.
"Piled Steel Cause Collapse".
59. Ottawa Journal, Ottawa, Ontario, April 1964.
"Four-Storey Collapse Probed".
60. Owen Sound Sun Times, Ontario, December 17, 1965.
"Six Are Buried In Wet Cement Near Montreal".
61. Klieger, P.
"Effects of Mixing and Curing Temperatures on
Concrete Strength".
Journal of the American Concrete Institute (ACI) Vol. 29,
No. 12, June 1958, Title No. 54-62, pp.1063-1081.

UNIVERSITY OF OTTAWA
LIBRARY

62. Sarnia Observer, Ontario, August 6, 1964.
"Roof Collapses Four Men Hurt".
63. Sudbury Star, Ontario, November 9, 1971.
"Roof For An Arena Collapses".
64. Taylor, P. J.
"Effects of Formwork Stripping Time On Deflections
of Flat Slabs and Plates".
Australian Civil Engineering and Construction, Vol. 8,
No. 2, February 1967, pp.31-35.
65. Telegraph, Toronto, Ontario, January 16, 1964.
"15 Die in Paris Flats Crash".
66. Telegram, Toronto, Ontario, October 7, 1963.
"6 Injured When School Floor Caves In".
67. Tisdale Recorder, Tisdale, Saskatchewan, December 11, 1963.
"One Dead In Collapse Of Skating Rink in Arborfield
Friday".
68. Toronto Daily Star, Ontario, September 21, 1971.
"Building Collapse Kills 3, 4th Man Found At Home".
69. Toronto Telegram, Ontario, April 15, 1971.
"Building Workers Escape As Roof Falls".
70. Toronto Telegram, Ontario, January 26, 1971.
"16 Storey Condominium Building Collapses in Boston".
71. Toronto Daily Star, Ontario, August 27, 1969.
"One Workman Killed On Job, Two Others Fall Seven
Storeys, Live".
72. Toronto Telegram, Ontario, May 7, 1968.
"Two Firms Charged In Slab Fall".
73. Trail Times, B. C., August 18, 1964.
"Material Said To Be Faulty In High School Construction".
74. Vancouver Sun, B.C., December 23, 1971.
"Two Escape Falling Roof".
75. Vancouver Sun, B.C., June 23, 1971.
"Concrete Floor Collapses".
76. Vancouver Sun, B.C., April 8, 1969.
"Baseball Dugout Collapses, Killing Little Leaguer's
Dad".

77. Vancouver Sun, B.C., September 7, 1966.
"6 Workmen Injured In Building Collapse".
78. Vancouver Sun, B.C., September 15, 1965.
"Two Buried In Concrete, 75 Carpenters Go Home".
79. Vancouver Sun, B.C., April 14, 1965.
"Building Collapse Bring Criticisms".
80. Vancouver Times, B.C., April 8, 1965.
"Building Plunge Fatal".
81. Windsor Star, Ontario, September 21, 1971.
"Three Kitchener Workers Killed As Wall Collapses".
82. Windsor Star, Ontario, December 17, 1964.
"Subway Collapse Injures 15".

UNIVERSITY OF
VANCOUVER LIBRARY

APPENDIX 1

Some of the structure failures during construction in Canada and U.S.A. during the past eight years, which are investigated from restored news-papers record etc. in building research branch of NRC.

After the structure collapses, it is sometimes difficult to find out the actual cause of failure and therefore in some of the mishaps listed in Figure 1, the cause of failure could not be given. It is observed that the main causes of failure in most of the cases are such as listed on pages 2 and 3.

FIGURE 1
SOME OF THE FAILURES DURING CONSTRUCTION IN CANADA AND U.S.A.
DURING THE PAST EIGHT YEARS

No.	Structure	Location	Year of Failure	Probable Cause of Failure
1	Warehouse Building	Delta at 9467-120th St. Vancouver	Dec. 1971	Roof trusses were not braced
2	Roof of Laundromat	Calgary, Alta.	Dec. 1971	-
3	Floor of Volkswagon Assembly Plant	Edmonton, Alta.	Nov. 1971	-
4	Roof for an arena	Calgary, Alta.	Nov. 1971	-
5	Roof of Fairview Community Centre	Calgary, Alta.	Nov. 1971	High wind
6	Newly poured section of the building	Kitchener, Ont.	Sept. 1971	-
7	Sherbrooke Highway Project (overpass)	Montreal, Que.	July, 1971	Temp. Supports: 1) Not strong enough; 2) Not spaced properly
8	Conc. floor of an apartment building	Burrard & Tenth Vancouver	July, 1971	Steady rain weakens the shores
9	U/D Parking Garage of 22-storey partly completed apartment building	Toronto, Ont.	April, 1971	-

FIGURE 1 - Continued

No.	Structure	Location	Year of Failure	Probable Cause of Failure
10	Conc. overpass	San Bruno, Calif. U.S.A.	April, 1971	Steel scaffold may have buckled or been displaced.
11	Conc. highway overpass	London, England	April, 1971	Scaffold collapsed
12	Garage	Arlington, Va. U.S.A.	March, 1971	Formwork collapsed
13	16-storey Condominium Building	Boston, Mass. U.S.A.	Jan. 1971	1) Formwork; 2) Heavy piece of equipment; 3) Conc. strength
14	Roof in new Faculty of Music building at U.W.O.	London, Ont.	Dec. 1970	Formwork
15	Overpass	15 mi. from Los Angeles, U.S.A.	Aug. 1970	Formwork
16	Cantilever box girder bridge "Milford Haven Road Bridge"	South West Wales	July, 1970	-
17	Freeway Bridge	Baldwin Park Los Angeles, U.S.A.	May 1970	Support collapsed
18	Jet Engine Testing Bldg.	International Airport, San Francisco, U.S.A.	Feb. 1970	No shoring under the roof section that collapsed
19	Nevada overpass collapse	Bet. Reno & Carson City, Nev., U.S.A.	Sept. 1969	Wooden falsework

FIGURE 1 - Continued

No.	Structure	Location	Year of Failure	Probable Cause of Failure
20	Balcony of 22-storey building	Buenos Aires, S.A.	Aug. 1969	Premature form removal and improper curing of conc.
21	Hogg's Hollow apartment building	Toronto, Ont.	Aug. 1969	Scaffold collapses
22	North Star Inn	Winnipeg, Portage Ave.	May 1969	-
23	Basevall Dugout	Vancouver, B.C.	April, 1969	No reshoring
24	Hospital project	Pittsburgh, Pa., U.S.A.	March, 1969	Shores collapse
25	Warehouse roof	Queensdale Road, Ottawa, Ont.	June 1968	Roof supports fell
26	Crystal Mall office building	Arlington, Va. U.S.A.	June 1968	Insufficient lateral & diagonal bracing
27	Conc. slab of the building	Bay and Bloor Toronto, Ont.	May 1968	Insufficient bracing
28	Excavation Cave	Otoc County, 40 mi. south of Omaha, Neb., U.S.A.	May 1968	Not properly shored
29	8-lane bridge at Worcester	Mass, U.S.A.	April, 1968	-
30	Student Union Bldg. at Univ. of North Carolina	Chapel Hill at Frank Porter Graham	Jan. 1968	Faulty or inadequate supports

FIGURE 1 - Continued

No.	Structure	Location	Year of Failure	Probable Cause of Failure
31	Secrecy Veils Bridge	Near Mexico City, U.S.A.	Dec. 1967	When dismantling the formwork
32	Roof of Library Bldg.	Fort Worth, Tex., U.S.A.	May 1967	Formwork collapsed
33	Bridge on drainage channel on Columbia Street	B.C.	Jan. 1967	Stringer rots and falls down
34	Roof of the Civic Centre	Toronto, Ont.	Oct. 1966	-
35	Concrete Dome	Vegreville, Alta.	Oct. 1966	Lack of diagonal bracing with false formwork
36	Conc. roof slab at Erie Conc. Prod.Ltd. Plant	London, Ont.	Sept. 1966	-
37	Floor of a private office building	Boston, Mass., U.S.A.	Sept. 1966	-
38	Heron Road bridge	Ottawa, Ont.	Aug. 1966	Inadequate diagonal and other bracing
39	Floor slab of expansion of paper mill	Athens, Greece	May 1966	Splicing 3 timber lengths to form 29' shores without proper bracing
40	Steel frame dome	Kingston, Jamaica	May 1966	Premature removal of temp. falsework supporting the central compression ring

FIGURE 1 - Continued

No.	Structure	Location	Year of Failure	Probable Cause of Failure
41	Dallas Trade Mart Bldg., (R.C.C. Cantilever Const.)	Dallas, Tex. U.S.A.	May 1966	
42	Maryland Cave-in		May 1966	Unshored storm drain-trench caved in
43	Wall, Moyer & Diebel Metal Craft Ltd.	Beamsville, Ont.	May 1966	No bracing supporting 136' long wall
44	Elgin St. apartment bldg.	Ottawa, Ont.	Mar. 1966	Piled steel, lack of reinforcing bars
45	Railway tunnel (Montreal Trans-Canada Highway Project)	Montreal, Que.	Dec. 1965	Formwork collapsed
46	20'x20' section of the 3rd floor of structure at Hjorth & Johnson Rds.	Surrey, England	Sept. 1965	-
47	Huge curved roof str. for warehouse at MacMillan	Vancouver, B.C.	Apr. 1965	Inadequate bracing of roof trusses
48	Montreal's Subway Project (wooden & steel roof frame)	Montreal, Que.	Dec. 1964	Roof supports suddenly gave-way
49	LDS Church roof	Calgary, Alta.	Oct. 1964	Gust of wind, 2 out of 32 trusses toppled
50	Tower (1-1/2 m. gallon water)	Fort St. John, Alta.	Sept 1964	-
51	J. Lloyd Crowe Senior Secd. School (2nd fl. roof)	B.C.	Aug. 1964	Concrete was very weak

FIGURE 1 - Concluded

No.	Structure	Location	Year of Failure	Probable Cause of Failure
52	Roof of a water filtration plant	Near Terrebonne, Que.	Aug. 1964	-
53	Charlottetown Regional High School (portion of 3rd floor)	P.E.I.	June 1964	High wind
54	Eramosa Rd. Bridge		June 1964	When loosening some retaining ties
55	4th Floor of apartment building at Springland Dr., off Riverside Dr. at Mooney's Bay	Ottawa, Ont.	Apr. 1964	-
56	12-storey steel & conc. frame-work of a block of flats in Central Paris	Paris, France	Jan. 1964	-
57	Roof of Arborfield rink building project	Arborfield, Sask.	Dec. 1963	While shifting the rafter-raising equipment
58	Floor while pouring collapsed, Parkdale Collegiate Institute	Toronto, Ont.	Oct. 1963	-
59	Load bearing wall for a 2-storey wing of Daviess County Court House	Owensboro, Ky. U.S.A.	July 1963	Excessive unbraced length may be the cause
60	15-floor apartment bldg., 10th & 11th floors collapsed	London, Ont.	Feb. 1963	-

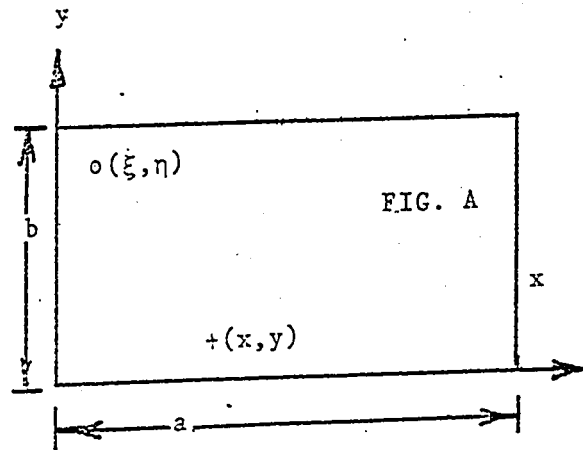
APPENDIX 2

NUMERICAL ANALYSIS BY NIELSEN

Mathematical derivation of finding the load ratios apply to adjacent components (shores, slabs) as taken from Nielsen's paper (Ref. 54).

Nomenclature used in the analysis

a and b = The length of the edges of the slab in the directions x and y respectively (see Fig. A).



h = Thickness of the slab
α = The density of the slab
q' = The dead weight per unit area of the slab

- $E^{(w)}$ = The modulus of elasticity at the age of w days after placing the concrete
- ν = Poisson's ratio
- $N_s^{(w)}$ = The modulus of the slab $N_s^{(w)} = \frac{E^{(w)} \cdot h^3}{12(1 - \nu^2)}$ at the age of w days after placing the concrete
- $W^{(w)}(x,y)$ = The additional deformation of the slab at right angles to the plane of the slab at the age of w days after placing of concrete
- $W_q^{(w)}(x,y)$ = The additional deformation of the slab due to the load q at the age of w days after placing the concrete
- $W_n(x,y)$ = The n -th normalized characteristic function of the slab
- X_{n2} = The value of n -th root of the equation of frequency of the slab
(The angular frequency $\omega_n = X_n^2 \sqrt{N_s} / ah$)
- $\lambda_n^{(w)}$ = The n -th characteristic value $(\lambda_n^{(w)} = X_n^4 N^{(w)})$ at the age of w days after placing the concrete
- A_n = $\int_0^a \int_0^b W_n \, dx \, dy$
- $K^{(w)}(x,y,\xi,\eta)$ = The influence function of the slab (the nucleus of an integral equation) at an age of w days after placing the concrete. This function expresses the deflection at the point (x,y) due to unit load at the pt. (ξ,η)
- $p^{(w)}(x,y)$ = The additional load on formwork at an age of w days after placing the concrete

k	= The coefficient of compression of the form-work (the force per unit area of the form-work which is required in order to produce a deformation of unit length in a vertical direction
K	= Load intensity that produces unit deformation of the support
m	= Number of levels of shores
N	= Time between placing of a fresh slab and the removal of the props from above the lowest slab in the system
E_s	= Modulus of elasticity of reinforcement
E_c	= Modulus of elasticity of concrete
Mu	= Ultimate design resisting moment
d	= Effective depth of the member
f'_c	= Crushing strength of concrete
f_y	= Yield stress of steel
As	= Area of steel bar
δ	= Deflection
I	= Moment of inertia
L	= Span
P_b	= Reinforcement ratio producing balanced conditions at ultimate strength
P_u	= Ultimate load
ϵ_s	= Steel strain
ϵ_c	= Concrete strain

NIELSEN'S Method (Ref. 54)

The method employed in the analysis is illustrated schematically in Fig. 2. After laying the foundations, the formwork is erected for the walls and floor slabs of the first storey. Then the walls are cast, and a few days later when the concrete of the walls has hardened, the first floor slab is cast (stage No. 1). The number of days given in the following are reckoned from this day. The erection of the formwork for the next storey is started a few days later, and under favourable conditions, the second floor slab can be cast 6 to 7 days after the first floor slab (stage No. 2). The third floor slab is cast a week after that (stage No. 3). Now the first formwork is removed (e.g. after 15 days) for further use (stage No. 4). The fourth floor slab is cast after 21 days (stage No. 5), and so on. Subsequently, 3 or 4 floor slabs are alternatively coupled.

For analysis purposes, the first seven stages corresponding to the rate of construction as described above are considered, and expressions for additional load acting on the formwork and additional moments applied to the floor slabs in each stage are deduced as under:

STAGE NO. 1

Stage No. 1 Day 0
Casting of Slab 1
0 days



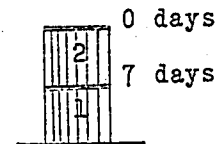
The first floor slab has newly been cast and due to the assumption that shrinkage and creep is neglected, which

follows that the concrete of the slab will harden during the next few days without being submitted to any moments at all. The load acting on the formwork is uniformly distributed and thus can be written as:

$$p^{(0)}(x,y) = q$$

Stage No.2 Day 0
Casting of Slab 2

STAGE NO. 2



The next floor slab is cast a week later. The dead weight of this slab will be partially carried by the slab situated below and partly by the formwork of the later slab, which is assumed to rest on a perfectly rigid support.

Now we have to calculate the load distribution $p^{(7)}(x,y)$ in the lower formwork which is caused by the additional load due to upper floor slab.

If the characteristic functions of a slab under any arbitrary boundary conditions are normalized in such a manner that $\int_0^a \int_0^b w_n dx dy = 1$, then the influence function can be written in the well-known form

$$K(x,y,\xi,\eta) = \sum_n \frac{1}{\lambda_n} w_n(x,y) w_n(\xi,\eta)$$

$n = 1, 2, 3, \dots$

Now the deformation due to a uniformly distributed load q per unit area is

$$w_q(x,y) = q \int_0^a \int_0^b K(x,y,\xi,\eta) d\xi d\eta = q \sum_n \frac{1}{\lambda_n} w_n(x,y) \int_0^a \int_0^b w_n(\xi,\eta) d\xi d\eta$$

Introducing the notation

$$A_n = \int_0^a \int_0^b w_n(\xi, \eta) d\xi d\eta$$

we obtain the deformation expression:

$$w_q(x, y) = q \sum_n \frac{A_n}{\lambda_n} w_n(x, y) \quad n = 1, 3, 5, \dots$$

The characteristic functions of an even order are supposed to be antisymmetrical. In that case A_n becomes zero for these functions. Consequently, every second characteristic function in the expression for $w_q(x, y)$ will vanish.

The additional deformation $w^{(7)}(\xi, \eta)$ of the lower floor slab gives rise to the reaction $k w^{(7)}(\xi, \eta)$ in the elastic support. So we obtain:

$$w^{(7)}(x, y) = w_q^{(7)}(x, y) - k \int_0^a \int_0^b K^{(7)}(x, y, \xi, \eta) w^{(7)}(\xi, \eta) d\xi d\eta$$

This is an inhomogeneous linear integral equation having a symmetrical nucleus.

Now if we imagine $w^{(7)}(x, y)$ and $w^{(7)}(\xi, \eta)$ to be expanded into the series which are built up by means of characteristic functions of the slab:

$$w^{(7)}(x, y) = \sum_n c_n^{(7)} w_n(x, y)$$

and $w^{(7)}(\xi, \eta) = \sum_n c_n^{(7)} w_n(\xi, \eta)$ respectively. After insertion of these expressions, the sign of summation can be deleted. The coefficients of even order vanish, and we get

$$c_n^{(7)} = \frac{\frac{q}{k} A_n}{\left(1 + \frac{\lambda_n}{k}\right)}$$

$$n = 1, 3, 5, \dots$$

In order to determine the additional moment acting on the floor slab, we can start from the deformation

$$w_n^{(7)}(x, y) = \frac{q}{k} \left[\frac{A_n}{\left(1 + \frac{\lambda_n}{k}\right)} w_n(x, y) \right]$$

$$n = 1, 3, 5, \dots$$

Then the additional load on the formwork is

$$p^{(0)}(x, y) = q$$

and

$$p_n^{(7)}(x, y) = k w_n^{(7)}(x, y) = q \left[\frac{A_n}{\left(1 + \frac{\lambda_n}{k}\right)} w_n(x, y) \right]$$

$$n = 1, 3, 5, \dots$$

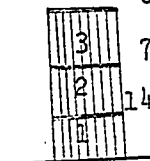
STAGE NO. 3

Stage No.3 Day 14
Casting of Slab 3

0 days

7 days

14 days



The third floor slab is cast one week after the second. The load due to the newly placed concrete is uniformly distributed over the second floor slab, which is now one week old. The second floor slab is deformed, and the part of the load is transmitted through the formwork to the first floor slab, which is now two weeks old. Just as before, we consider the effect of the additional load only. Then the deformation of the floor slab No. 2 can be written as:

$$w^{(7)}(x,y) = w_q^{(7)}(x,y) - k \int_0^a \int_0^b K^{(7)}(x,y,\xi,\eta) |w^{(7)}(\xi,\eta) - w^{(14)}(\xi,\eta)| d\xi d\eta$$

where $k|w^{(7)}(\xi,\eta) - w^{(14)}(\xi,\eta)|$ denotes the upward load $p^{(7)}(\xi,\eta)$ per unit area of the formwork at the pt. $x = \xi, y = \eta$.

Now the deformation of the floor slab No. 1 is written

$$w^{(14)}(x,y) = \int_0^a \int_0^b K^{(14)}(x,y,\xi,\eta) |p^{(7)}(\xi,\eta) - kw^{(14)}(\xi,\eta)| d\xi d\eta$$

By above analogy, we assume as:

$$w^{(7)}(x,y) = \sum c_n^{(7)} w_n(x,y)$$

and

$$w^{(14)}(x,y) = \sum c_n^{(14)} w_n(x,y)$$

By inserting these into the expressions for $w^{(7)}$ and $w^{(14)}$ we get:

$$c_n^{(7)} \left(1 + \frac{\lambda_n^{(7)}}{k} \right) - c_n^{(14)} = \frac{q}{k} A_n$$

and

$$c_n^{(7)} = \left(2 + \frac{\lambda_n^{(14)}}{k} \right) c_n^{(14)}$$

By solving the above two, we have:

$$c_n^{(7)} = \frac{\left(2 + \frac{\lambda_n^{(14)}}{k} \right) \frac{q}{k} A_n}{\left(1 + \frac{\lambda_n^{(7)}}{k} \right) \left(2 + \frac{\lambda_n^{(14)}}{k} \right) - 1}$$

and

$$c_n^{(14)} = \frac{\frac{q}{k} A_n}{\left(1 + \frac{\lambda_n^{(7)}}{k} \right) \left(2 + \frac{\lambda_n^{(14)}}{k} \right) - 1}$$

Thus the additional deformation can be calculated and thus additional moments can be determined. The additional load on the formwork is:

$$p^{(0)}(x,y) = q$$

$$p^{(7)}(x,y) = k \left| w^{(7)}(x,y) - w^{(14)}(x,y) \right|$$

$$= q \sum \frac{\left(1 + \frac{\lambda_n^{(14)}}{k}\right) A_n}{\left[1 + \frac{\lambda_n^{(7)}}{k}\right] \left[2 + \frac{\lambda_n^{(14)}}{k}\right] - 1} w_n(x,y)$$

$$n = 1, 3, 5, \dots$$

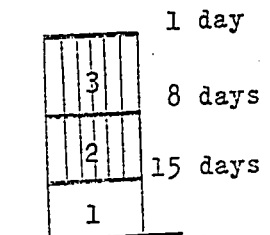
and

$$p^{(14)}(x,y) = k w^{(14)}(x,y) = q \sum \frac{A_n}{\left[1 + \frac{\lambda_n^{(7)}}{k}\right] \left[2 + \frac{\lambda_n^{(14)}}{k}\right] - 1} w_n(x,y)$$

$$n = 1, 3, 5, \dots$$

Stage No. 4 Day 15
Removal of Formwork 1

STAGE NO. 4



The next stage takes place the following day, when the first formwork is removed. So the upward reaction caused by this formwork will vanish. In other words the system is submitted to a downward additional load of the same character as the total upward reaction due to the first form in stage No. 3. Neglecting the increase in the modulus of elasticity of concrete (E_c) during the preceding

day and in accordance with the previous calculations, the additional load is:

$$p^{(14)}(x,y) = q[B_n w_n(x,y)]$$

where

$$B_n = A_n \left[1 - \frac{1}{\left(1 + \frac{\gamma_n^{(7)}}{k}\right)} - \frac{1}{\left(1 + \frac{\gamma_n^{(7)}}{k}\right)\left(2 + \frac{\gamma_n^{(14)}}{k}\right) - 1} \right]$$

Since this additional load is directed downwards, we imagine that the formwork is subjected to tensile stresses. For floor slab No. 2, the deformation is given by:

$$w^{(7)}(x,y) = k \int_0^a \int_0^b K^{(7)}(x,y,\xi,\eta) \left| w^{(14)}(\xi,\eta) - w^{(7)}(\xi,\eta) \right| d\xi d\eta$$

and deformation for floor slab No. 1 is:

$$w^{(14)}(x,y) = \int_0^a \int_0^b K^{(14)}(x,y,\xi,\eta) \left| p^{(14)}(\xi,\eta) - k \{ w^{(14)}(\xi,\eta) - w^{(7)}(\xi,\eta) \} \right| d\xi d\eta$$

If we assume the functions as before, i.e.

$$w^{(7)}(x,y) = \sum C_n^{(7)} w_n(x,y)$$

$$w^{(14)}(x,y) = \sum C_n^{(14)} w_n(x,y)$$

we get:

$$C_n^{(14)} = \left(1 + \frac{\gamma_n^{(7)}}{k}\right) C_n^{(7)}$$

$$C_n^{(14)} = \left(1 + \frac{\gamma_n^{(14)}}{k}\right) = \frac{q}{k} B_n + C_n^{(7)}$$

By solving, we have:

$$C_n^{(7)} = \frac{\frac{q}{k} B_n}{(1 + \frac{\gamma_n}{k})(1 + \frac{\gamma_n}{k}) - 1} \quad (14)$$

and

$$C_n^{(14)} = \frac{\frac{q}{k} B_n (1 - \frac{\gamma_n}{k})}{(1 + \frac{\gamma_n}{k})(1 + \frac{\gamma_n}{k}) - 1} \quad (14)$$

Thus the additional deformation is known and additional moments can be determined.

The additional load on the formwork is:

$$p^{(0)}(x,y) = 0$$

$$p^{(7)}(x,y) = k[w^{(7)}(x,y) - w^{(14)}(x,y)]$$

$$= q \int \frac{-\frac{\gamma_n}{k} B_n}{(1 + \frac{\gamma_n}{k})(1 + \frac{\gamma_n}{k}) - 1} w_n(x,y)$$

$$n = 1, 3, 5, \dots$$

STAGE NO. 5

Stage No. 5 Day 21
Casting of Slab 4

4	0 days
3	7 days
2	14 days
1	21 days

As shown, the fourth slab is cast at 21 days. By analogy with the above, we have:

$$w^{(7)}(x,y) = w_q^{(7)}(x,y) - k \int_0^a \int_0^b K^{(7)}(x,y,\xi,\eta) |w^{(7)}(\xi,\eta) - w^{(14)}(\xi,\eta)| d\xi d\eta$$

$$w^{(14)}(x,y) = k \int_0^a \int_0^b K^{(14)}(x,y,\xi,\eta) |w^{(7)}(\xi,\eta) - 2w^{(14)}(\xi,\eta) + w^{(21)}(\xi,\eta)| d\xi d\eta$$

$$\text{and } w^{(21)}(x,y) = k \int_0^a \int_0^b K^{(21)}(x,y,\xi,\eta) |w^{(14)}(\xi,\eta) - w^{(21)}(\xi,\eta)| d\xi d\eta$$

Assuming the similar functions, we have:

$$w^{(7)}(x,y) = \sum c_n^{(7)} w_n(x,y)$$

$$w^{(14)}(x,y) = \sum c_n^{(14)} w_n(x,y)$$

$$w^{(21)}(x,y) = \sum c_n^{(21)} w_n(x,y)$$

By substituting the above function we have:

$$c_n^{(7)} \left(1 + \frac{\gamma_n^{(7)}}{k}\right) - c_n^{(14)} = \frac{a}{k} A_n$$

$$c_n^{(14)} \left(2 + \frac{\gamma_n^{(14)}}{k}\right) = c_n^{(7)} + c_n^{(21)}$$

$$\text{and } c_n^{(21)} \left(1 + \frac{\gamma_n^{(21)}}{k}\right) = c_n^{(14)}$$

By solving these, we finally get:

$$c_n^{(21)} = \frac{\frac{a}{k} A_n}{\left|1 + \frac{\gamma_n^{(7)}}{k}\right| \left| \left(1 + \frac{\gamma_n^{(21)}}{k}\right) \left(2 + \frac{\gamma_n^{(14)}}{k}\right) - 1 \right| - \left|1 + \frac{\gamma_n^{(21)}}{k}\right|}$$

$$c_n^{(14)} = \left(1 + \frac{\gamma_n^{(21)}}{k}\right) c_n^{(21)}$$

and

$$c_n^{(7)} = \left| \left(1 + \frac{\gamma_n^{(21)}}{k}\right) \left(2 + \frac{\gamma_n^{(14)}}{k}\right) - 1 \right| c_n^{(21)}$$

Thus the additional deformation is known and additional moments can be calculated.

Now the additional load on the formwork is:

$$p^{(0)}(x,y) = q$$

$$p^{(7)}(x,y) = k |w^{(7)}(x,y) - w^{(14)}(x,y)|$$

$$= q \sum \frac{\left| \left(1 + \frac{\gamma_n^{(21)}}{k}\right) \left(1 + \frac{\gamma_n^{(14)}}{k}\right) - 1 \right|}{\left| 1 + \frac{\gamma_n^{(7)}}{k} \right| \left| \left(1 + \frac{\gamma_n^{(21)}}{k}\right) \left(2 + \frac{\gamma_n^{(14)}}{k}\right) - 1 \right| - \left| 1 + \frac{\gamma_n^{(21)}}{k} \right|} w_n^{(x,y)}$$

and

$$n = 1, 3, 5, \dots$$

$$p^{(14)}(x,y) = k |w^{(14)}(x,y) - w^{(21)}(x,y)|$$

$$= q \sum \frac{\frac{\gamma_n^{(21)}}{k} A_n}{\left| 1 + \frac{\gamma_n^{(7)}}{k} \right| \left| \left(1 + \frac{\gamma_n^{(21)}}{k}\right) \left(2 + \frac{\gamma_n^{(14)}}{k}\right) - 1 \right| - \left| 1 + \frac{\gamma_n^{(21)}}{k} \right|} w_n^{(x,y)}$$

$$n = 1, 3, 5, \dots$$

STAGE NO. 6

Stage No. 6 Day 22
Removal of Formwork 2

4	1 day
3	8 days
2	15 days
1	22 days

The next stage takes place on the following day, when formwork No. 2 is removed. Now the upward reaction due to this formwork will vanish. By analogy with Stage No. 4, it can be said that the system is subjected to a downward additional load equal to the upward reaction caused by form No. 2 in Stage No. 5. Neglecting the gain in the modulus of elasticity during the preceding day, we have the additional loads as per previous calculations:

$$p^{(14)}(x,y) = q[B_n^* w_n(x,y)]$$

where

$$B_n^* = A_n + \frac{(1 + \frac{\lambda_n^{(14)}}{k}) A_n^{(14)}}{(1 + \frac{\lambda_n^{(7)}}{k})(2 + \frac{\lambda_n^{(14)}}{k}) - 1} + \frac{-\frac{\lambda_n^{(7)}}{k} B_n^{(14)}}{(1 + \frac{\lambda_n^{(7)}}{k})(1 + \frac{\lambda_n^{(14)}}{k}) - 1} + \frac{\frac{\lambda_n^{(21)}}{k} A_n^{(14)}}{\left| 1 + \frac{\lambda_n^{(7)}}{k} \right| \left| (1 + \frac{\lambda_n^{(21)}}{k})(2 + \frac{\lambda_n^{(14)}}{k}) - 1 \right| - \left| 1 + \frac{\lambda_n^{(21)}}{k} \right|}$$

The following calculations are completely analogous to those made in the Stage No. 4, and the results can be written directly.

As before the assumed functions are:

$$w^{(7)}(x,y) = \sum c_n^{(7)} w_n(x,y)$$

$$w^{(14)}(x,y) = \sum c_n^{(14)} w_n(x,y)$$

By solving we get:

$$c_n^{(7)} = \frac{\frac{a}{k} B_n^*}{\left(1 + \frac{\lambda_n^{(7)}}{k}\right) \left(1 + \frac{\lambda_n^{(14)}}{k}\right) - 1}$$

$$c_n^{(14)} = \frac{\frac{a}{k} B_n^* \left(1 + \frac{\lambda_n^{(7)}}{k}\right)}{\left(1 + \frac{\lambda_n^{(7)}}{k}\right) \left(1 + \frac{\lambda_n^{(14)}}{k}\right) - 1}$$

Thus the additional deformation is known and additional moments can be calculated.

The additional load on the form is:

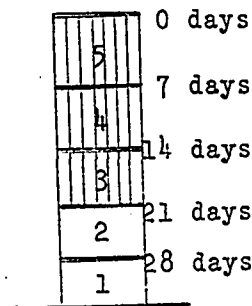
$$p^{(0)}(x,y) = 0$$

$$p^{(7)}(x,y) = a \sum \frac{-\frac{\lambda_n^{(7)}}{k} B_n^*}{\left(1 + \frac{\lambda_n^{(7)}}{k}\right) \left(1 + \frac{\lambda_n^{(14)}}{k}\right) - 1} w_n(x,y)$$

$$n = 1, 3, 5, \dots$$

STAGE NO. 7

Stage No. 7 Day 28
Casting of Slab 5



This stage is reached 28 days after the beginning of construction, and corresponds to the casting of the 5th slab.

This stage is completely analogous to Stage No. 5 and consequently, the expressions for $p^{(m)}(x,y)$ and $w^{(m)}(x,y)$ can generally be written in the form:

$$p^{(m)}(x,y) = q \sum C_n^{(m)} w_n(x,y) \quad (1)$$

and

$$w^{(m)}(x,y) = \frac{q}{k} \sum D_n^{(m)} w_n(x,y) \quad (2)$$

where the coefficients of expansion $C_n^{(m)}$ and $D_n^{(m)}$ contain $\frac{\lambda_n^{(m)}}{k}$ and A_n only.

The formulae deduced above can also be applied to a strip of a slab or to a beam. In that case we have:

$$\lambda_n^{(m)} = E^{(m)} I X_n^4$$

and $w_n(x,y)$ should be replaced by the characteristic functions of the beam $w_n(x)$.

The coefficient of compression k can be written as

$$k = \frac{1}{\delta}$$

where $\delta = \sum \frac{Pt}{AE}$ = vertical deformation of the formwork at a unit load per unit form area.

UNIVERSITY LIBRARY

Simplified Expressions for Numerical Calculation

For beams, the expressions (1) and (2) above can be written as:

$$p^{(m)}(x) = q \sum_n C_n^{(m)} w_n(x) \quad n = 1, 3, 5, \dots \quad (3)$$

$$w^{(m)}(x) = \frac{q}{k} \sum_n D_n^{(m)} w_n(x) \quad n = 1, 3, 5, \dots \quad (4)$$

Simply Supported Beam

The normalized characteristic function can be written as:

$$w_n(x) = \sqrt{\frac{2}{a}} \sin \frac{n\pi}{a} x = \sqrt{\frac{1}{a}} U_n(x) \quad (5)$$

where

$$U_n(x) = \sqrt{2} \sin \frac{n\pi}{a} x \quad (6)$$

$$\chi_n = \frac{n\pi}{a} \quad \text{or} \quad \chi_n a = n\pi \quad (7)$$

By substituting (5) in (3), we get:

$$p^{(m)}(x) = q \sum_n \frac{C_n^{(m)}}{\sqrt{a}} U_n(x) \quad n = 1, 3, 5, \dots \quad (8)$$

Now the moment acting on the beam is calculated from

$$M^{(m)}(x) = -E^{(m)} I \frac{d^2 w_n(x)}{dx^2} \quad (9)$$

By substituting eqs. (4) and (5) in eq. (8), we get:

$$M^{(m)}(x) = -q \frac{E^{(m)} I}{k} \sum_n \frac{D_n^{(m)}}{\sqrt{a}} \frac{d^2 U_n(x)}{dx^2} \quad n = 1, 3, 5, \dots \quad (10)$$

Thus we have

$$\frac{d^2 U_n(x)}{dx^2} = \chi_n^2 u_{*n}''(x) \quad (11)$$

$$\text{where } u_{*n}''(x) = -\sqrt{2} \sin \frac{n\pi}{a} x = -U_n(x) \quad (12)$$

Now by substituting eq. (11) in eq. (10), we get:

$$M_n^{(m)}(x) = -q \frac{E_n^{(m)} I}{ka^2} \int (\chi_n a)^2 \frac{D_n^{(m)}}{\sqrt{a}} U_{*n}''(x) \quad (13)$$

$$n = 1, 3, 5, \dots$$

The expressions (8) and (13) are the final expressions.

The mathematical form of the coefficients $\frac{C_n^{(m)}}{\sqrt{a}}$ and $\frac{D_n^{(m)}}{\sqrt{a}}$ comprise $\frac{\lambda_n^{(m)}}{k}$ and $\frac{A_n}{\sqrt{a}}$ only and can be deduced for different types of formwork and slabs under given rates of construction.

In accordance with the definition, we have:

$$\frac{\lambda_n^{(m)}}{k} = \frac{E_n^{(m)} I \chi_n^4}{k} \quad (14)$$

and

$$A_n = \int_0^a w_n(x) dx \quad (15)$$

By substituting eq. (5) in eq. (15), we get

$$\frac{A_n}{\sqrt{a}} = \frac{\sqrt{2}}{n\pi} (1 - \cos n\pi) \quad n = 1, 3, 5, \dots \quad (16)$$

Built-In Beam

Expressions (8) and (13) are also applicable to

a built-in beam.

The normalized characteristic function can be

written:

$$w_n(x) = \sqrt{\frac{1}{a}} U_n(x) \quad (17)$$

where

$$U_n(x) = |\cosh \chi_n x - \cos \chi_n x - a_n(\sinh \chi_n x - \sin \chi_n x)| \quad (18)$$

and

$$a_n = \tanh \frac{\chi_n a}{2} \quad n = 1, 3, 5, \dots \quad (19)$$

The value of χ_n is obtained by the equation of frequency:

$$\text{i.e. } \cosh \chi_n a \cos \chi_n a = 1 \quad (20)$$

For the symmetrical characteristic function

$$U_n'' = \cosh \chi_n x + \cos \chi_n x - a(\sinh \chi_n x + \sin \chi_n x) \quad (21)$$

$$\text{Such that } \frac{A_n}{\sqrt{a}} = \frac{4a_n}{\chi_n a} \quad (22)$$

The maximum load ratio obtained by Nielsen was 2.66 on slab 2 at Stage No. 7.

APPENDIX 3

A. Calculation of Direct Load on Props (Shores)

Apartment Building at Alta Vista Drive, Ottawa

Assuming the weight of concrete = 150 lbs/cu.ft

Thickness of the slab = 8"

So the weight of slab = 100 lbs/sq.ft

Referring to Figure 21, p. 42.

1. Divide the slab between the four columns into the strips parallel to AB and at right angle to AB, and whose central lines pass through the columns and props, we have:

$$\text{Load on Prop No. 1} = 100 \times (3.5 \times 3.5) = 1,225 \text{ lbs}$$

$$\text{Load on Prop No. 2} = 100 \times (4.12 \times 3.5) = 1,442 \text{ lbs}$$

$$\text{Load on Prop No. 3} = (100) \times (3.5 \times 5) = 1,750 \text{ lbs}$$

$$\text{Load on Prop No. 4} = 100 \times (4.12 \times 5) = 2,060 \text{ lbs}$$

$$\text{Load on Prop No. 5} = 100 \times (3.5 \times 5) = 1,750 \text{ lbs}$$

$$\text{Load on Prop No. 6} = 100 \times (4.12 \times 5) = 2,060 \text{ lbs}$$

$$\text{Load on Prop No. 7} = 100 \times (3.5 \times 3.5) = 1,225 \text{ lbs}$$

$$\text{Load on Prop No. 8} = 100 \times (4.12 \times 3.5) = 1,442 \text{ lbs}$$

$$\text{Total Load} = 12,954 \text{ lbs}$$

$$\text{So average load} = \frac{12,954}{8} \approx 1,620 \text{ lbs}$$

2. Total number of columns and props supporting the slab under reference = 13 (Interior) + 17 (Exterior)

$$\text{So average load on each prop} = \frac{(20.5 \times 16.66) \times 100}{13 + \frac{17}{2}}$$

$$\approx 1,586 \text{ lbs}$$

By Moment Distribution (see pp.109-112)

3. Dividing the slab into the strips passing through columns and props and parallel to direction AB. (See Fig. 21, Page 42)

Then calculating the reactions by moment distributions as shown on pp. 109 - 112

Load on Prop Nos. 1 or 7 = 883.97 lbs

Load on Prop Nos. 2 or 8 = 1,044.52 lbs

Load on Prop Nos. 3 or 5 = 2,081.40 lbs

Load on Prop Nos. 4 or 6 = 2,446.95 lbs

.. Average load on 1 prop = $\frac{12,913.68}{8} = 1,614.21$ lbs

4. By approximate centre around the props

As shown shaded in Figure 21, pp.42

Load on Prop No. 1 = 1,225 lbs

Load on Prop Nos. 2 or 8 = 1,400 lbs

Load on Prop No. 3 = 2,275 lbs

Load on Prop Nos. 4 or 6 = 2,000 lbs

Load on Prop No. 5 = 2,025 lbs

Load on Prop No. 7 = 1,425 lbs

Average load on one prop = $\frac{13,750}{8} = 1,718.77$ lbs

Moment Distribution (Props 5 and 7)

w = 350 lbs/sq.ft.

(.77) (.23)

(286) (714)

(.43) (.57)

Distribution Factor

	A	B	C	D	E
	5'	5'	2'	5'	
1) F.E.M.	0	1,100.00	-730.00	730.00	-1,100.00
2) Bal.	0	-159.00	-211.00	-775.8	228.00
3) C.O.	0	0	-87.90	-105.50	0.0
4) Bal.	0	37.8	50.10	-77.80	50.4
5) C.O.	0	0	-38.90	25.05	0.00
6) Bal.	0	16.70	22.20	-31.40	22.35
7) C.O.	0	0	-15.70	11.10	0.00
8) Bal.	0	6.75	8.95	-13.90	9.00
9) C.O.	0	0	-6.95	4.47	0.00
10) Bal.	0	2.98	3.97	-5.56	4.00
11) C.O.	0	0	-2.78	1.98	0
12) Bal.	0	1.20	1.58	-2.32	1.60
13) C.O.	0	0	-1.16	0.79	0
14) Bal.	0	0.50	0.66	-0.71	.73
15) C.O.	0	0	.35	.33	0
16) Bal.	0	.15	.20	.44	.32
17) C.O.	0	0	.22	.10	0
18) Bal.	0	.09	.13	.08	.13
19) C.O.	0	0	.04	.06	0
20) Bal.	0	.017	.023	.077	.062
21) Total (ft lb)	0	1,007.19	-1007.19	360.29	-783.41
					0

$$R_A = \frac{350 \times 5}{2} - \frac{1,007.19}{5} = 875 - 202 = \underline{673 \text{ lbs}}$$

$$\begin{aligned} R_B &= (875 + 202) + (875 - (\frac{-1,007.19 + 360.29}{5})) \\ &= 1,077 + (875 + 129.40) = \underline{2,081.40 \text{ lbs}} \end{aligned}$$

$$\begin{aligned} R_C &= (875 - 129.40) + (\frac{350 \times 2}{2} - (\frac{-360.14 + 783.41}{2})) \\ &= 745.60 + 138.37 = \underline{883.97 \text{ lbs}} \end{aligned}$$

$$\begin{aligned} R_D &= (350 + 211.63) + (875 - (\frac{-783.41 + 0}{5})) \\ &= 561.63 + (875 + 156.68) = \underline{1,593.31 \text{ lbs}} \end{aligned}$$

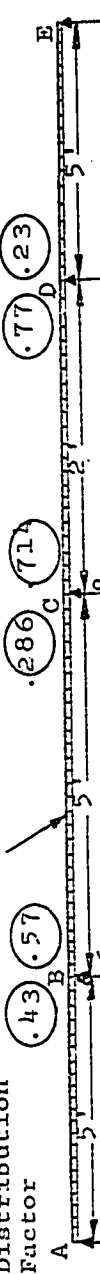
$$R_E = 875 + (\frac{-783.41 + 0}{5}) = 875 - 156.68 = \underline{718.32 \text{ lbs}}$$

UNIFIED LIBRARY

Moment Distribution Method (Props 6 and 8)

	A	B	C	D	E
1) F.E.M.	0	1,290.0	-860.0	860.0	-1,290.0
2) Bal.	0	-185.0	-245.0	-206.0	-265.0
3) C.O.	0	0	-103.0	-122.5	0.0
4) Bal.	0	44.3	58.7	-92.0	60.0
5) C.O.	0	0	-46.0	29.3	0.0
6) Bal.	0	19.8	27.2	-36.6	0.0
7) C.O.	0	0	-18.3	13.6	0.0
8) Bal.	0	7.86	10.4	-16.6	10.6
9) C.O.	0	0	-8.3	5.2	0.0
10) Bal.	0	3.57	4.73	-6.5	4.74
11) C.O.	0	0	-3.25	2.36	0.0
12) Bal.	0	1.40	1.85	-2.94	1.87
13) C.O.	0	0	-1.47	1.13	0.0
14) Bal.	0	.63	.84	-1.31	.84
15) C.O.	0	0	-.65	.42	0.0
16) Bal.	0	.28	.37	-.53	.37
17) C.O.	0	0	-.26	.18	0.0
18) Bal.	0	.11	.15	-.23	.15
19) C.O.	0	0	-.12	.08	0.0
20) Bal.	0	.05	.07	-.09	.07
21) Total (ft lbs)	0	-1,183.00	-1,182.04	427.27	-919.86

w = 412 lbs/sq.ft.



$$R_A = \frac{WL}{2} - \frac{M_A + M_B}{L} = \frac{412 \times 5}{2} - \frac{0 + 1,183}{5} = 1,030 - 236 = \underline{794 \text{ lbs}}$$

$$R_B = (1,030 + 236) + (1,030 - \frac{(-1,182.04 + 427.27)}{5})$$
$$= 1,266 + 1,180.95 = \underline{2,446.95 \text{ lbs}}$$

$$R_C = (1,030 - 150.95) + (\frac{412 \times 2}{2} - \frac{(-427.13 + 920.20)}{2})$$
$$= 879.05 + 165.47 = \underline{1,044.52 \text{ lbs}}$$

$$R_D = (412 + 246.53) + (1,030 - \frac{(-919.86 + 0)}{5})$$
$$= 658.53 + 1,213.97 = \underline{1,872.50 \text{ lbs}}$$

$$R_E = 1,030 + (\frac{919.86}{5}) = 1,030 - 184.00 = \underline{846.00 \text{ lbs}}$$

B. Calculation of Direct Load on Props (Reshores)

Apartment Building at Alta Vista Drive, Ottawa

Referring to Figure 22, page 43

Area of the slab shared by either of the Posts 1, 2, 3 or 4

$$\begin{aligned} &= \frac{5.12 \times 4.16}{2} + (\sqrt{5.12^2 + 4.16^2}) \\ &\quad \times (\sqrt{2.56^2 + 2.08^2}) \\ &= 10.63 + (6.6) \times (3.3) \\ &= 32.63 \text{ sq.ft.} \end{aligned}$$

Area of the slab shared by Post 5 = $6.6 \times 6.6 = 43.50 \text{ sq.ft.}$

Average load of the slab shared by either of the Post

$$\begin{aligned} &= \frac{(4 \times 32.63 + 43.50)}{5} \times 100 \text{ lbs} \\ &= \underline{3,480 \text{ lbs}} \end{aligned}$$

C. Calculation of Direct Load on Props (Shores)

Place du Portage, Hull, Quebec

Referring to Figure 48 page 57

Area of the slab shared by each post = $4 \times 3 = 12 \text{ sq.ft}$

Assuming the weight of concrete = 150 lbs/cu.ft

Thickness of the slab = 8"

So load taken by each post = $150 \times \frac{8}{12} \times 12$

$$= \underline{1,200 \text{ lbs}}$$

Formwork (10%)

$$= \underline{+ 120 \text{ lbs}}$$

$$\text{Total} = \underline{1,320 \text{ lbs}}$$

APPENDIX 4

Measured loads on the formwork during construction of the two flat-slab structures:

A. Apartment Building at Alta Vista Drive, Ottawa

Load on the formwork under the slab at level 7 to level 13 - Figures 22 to 25 respectively.

B. "Place Du Portage" in Hull, Quebec

Loads on the formwork under the slab at level 19 to level 22 - Figures 48 and 49

SHORES (CALCULATED LOADS IN LBS.)

POSTS	1	2	3	4	5	6	7	8		AVE.	L.R.
	1225	1400	2275	2000	2025	2000	1400	1400		1718	

FORM-WORK 10% OF SLAB LOAD ¹⁷²
TOTAL 1890 1.00

OPER. SHORES (MEASURED LOADS IN LBS.)

A-7	0	1405	1590	2565	2240	2295	2270	1595	1620		1948	1.03
B-5	1	1120	1275	2060	1825	1860	1810	1285	1300		1567	0.83
A-8	3	2240	2535	4100	3545	3700	3625	2556	2520		3115	1.65
B-6	4	1450	1650	2675	2360	2400	2355	1675	1635		2025	1.07
A-9	9	1825	2075	3370	2965	3020	2970	2100	2075		2550	1.35

RESHORES (CALCULATED LOADS IN LBS.)

POSTS	1	2	3	4	5	AVE.	L.R.
	3263	3263	3263	3263	4350	3480	

FORM-WORK 10% OF SLAB LOAD ³⁴⁸
TOTAL 3828 1.00

RESHORES (MEASURED LOADS IN LBS.)

B-7	10	470	450	435	515	620	498	0.13
A-10	11	1975	1885	1870	2160	2600	2098	0.55
B-8	14	435	410	405	455	605	462	0.12
A-11	23	1080	1010	1005	1100	1380	1115	0.29
B-9	24	335	315	305	340	405	340	0.09
A-12	28	330	305	305	320	470	346	0.09
B-10	29	325	310	310	315	475	347	0.09
A-13	31	290	280	285	280	400	307	0.08

MEASUREMENT OF LOADS ON THE FORM-WORK

UNDER THE SLAB AT LEVEL 7.

APARTMENT BUILDING AT ALTA-VISTA DR. OTTAWA.

FIG. NO.22

SHORES (CALCULATED LOADS IN LBS)

POSTS		1	2	3	4	5	6	7	8		AVE.	L.R.
		1225	1400	2275	2000	2025	2000	1400	1400		1718	

FORM-WORK 10% OF SLAB LOAD

172
TOTAL 1890 1-00

OPER. TIME SHORES (MEASURED LOADS IN LBS)

A-8	0	1335	1525	2475	2170	2215	2160	1540	1545		1870	0-99
B-6	1	1150	1310	2120	1870	1905	1875	1325	1295		1605	0-85
A-9	6	2045	2320	3765	3315	3380	3325	2340	2310		2850	1-51
B-7	7	1060	1200	1950	1715	1740	1720	1210	1185		1473	0-78
A-10	8	1930	2200	3565	3125	3200	3140	2200	2225		2698	1-43

RESHORES (CALCULATED LOADS IN LBS)

POSTS		1	2	3	4	5	AVE.	L.R.
		3263	3263	3263	3263	4350	3480	

FORM-WORK 10% OF SLAB LOAD

348
TOTAL 3828 1-00

RESHORES (MEASURED LOADS IN LBS)

B-8	11	498	492	465	535	690	536	0-14
A-11	20	1190	1175	1155	1230	1575	1265	0-33
B-9	21	465	460	445	505	610	497	0-13
A-12	25	685	665	655	705	930	728	0-19
B-10	26	325	310	320	345	420	344	0-09
A-13	28	325	315	315	350	425	346	0-09

MEASUREMENT OF LOADS ON THE FORM-WORK

UNDER THE SLAB AT LEVEL 8

APARTMENT BUILDING AT ALTA-VISTA DR. OTTAWA.

FIG. NO. 23

SHORES (CALCULATED LOADS IN LBS)

POSTS		1	2	3	4	5	6	7	8		AVE.	L.R.
		1225	1400	2275	2000	2025	2000	1400	1400		1718	
FORM-WORK 10% OF SLAB LOAD											172	
											1890	1.00
OPER. TIME SHORES (MEASURED LOADS IN LBS)												
A-9	0	1370	1550	2525	2200	2260	2225	1565	1555		1908	1.01
B-7	1	1135	1270	2060	1800	1875	1815	1305	1260		1565	0.83
A-10	2	2635	2615	4160	3750	3825	3545	2660	2510		3213	1.70
B-8	5	1120	1255	2040	1790	1845	1805	1275	1240		1546	0.82
A-11	14	1715	1940	3135	2775	2830	2785	1970	1870		2378	1.26
RESHORES (CALCULATED LOADS IN LBS)												
POSTS		1	2	3	4	5	AVE.		L.R.			
		3263	3263	3263	3263	4350	3480					
FORM-WORK 10% OF SLAB LOAD											348	
											TOTAL 3820	1.00
RESHORES (MEASURED LOADS IN LBS)												
B-9	15	575	570	565	585	775	614		0.16			
A-12	19	1455	1430	1415	1450	1915	1533		0.40			
B-10	20	435	420	405	470	570	460		0.12			
A-13	22	1150	1100	1090	1115	1480	1187		0.31			

MEASUREMENT OF LOADS ON THE FORM-WORK

UNDER THE SLAB AT LEVEL 9

APARTMENT BUILDING AT ALTA-VISTA DR. OTTAWA.

FIG. NO. 24

SHORES (CALCULATED LOADS IN LBS.)

POSTS		1	2	3	4	5	6	7	8		AVE	L.R.
		1225	1400	2275	2000	2025	2000	1400	1400		1718	
FORM-WORK 10% OF SLAB LOAD										172		
										TOTAL	1890	1.00
OPER. SHORES (MEASURED LOADS IN LBS)												
A-10	0	1425	1605	2610	2300	2390	2305	1645	1570		1980	1.05
B-8	3	905	960	1570	1385	1420	1390	975	925		1191	0.63
A-11	12	1870	2105	3415	3000	3110	3015	2140	2055		2589	1.37
B-9	13	985	1135	1820	1605	1640	1635	1125	1070		1377	0.73
A-12	17	1775	2005	3270	2880	2965	2855	2060	1970		2475	1.31
RESHORES (CALCULATED LOADS IN LBS.)												
POSTS		1	2	3	4	5	AVE.		L.R.			
		3263	3263	3263	3263	4350	3480					
FORM-WORK 10% OF SLAB LOAD										348		
										TOTAL	3820	1.00
RESHORES (MEASURED LOADS IN LBS)												
B-10	18	610	595	605	620	820	650		0.17			
A-13	20	1975	1915	1935	2015	2685	2105 ^g		0.55			

MEASUREMENT OF LOADS ON THE FORM-WORK

UNDER THE SLAB AT LEVEL 10

APARTMENT BUILDING AT ALTA-VISTA DR. OTTAWA

FIG. NO. 25

SHORES (CALCULATED LOADS IN LBS)

POSTS		1	2	3	4	5	6	7	8		AVE	L.R.
		1225	1400	2275	2000	2025	2000	1400	1400		1718	
FORM-WORK 10% OF SLAB LOAD "MEASURED LOADS IN LBS."										172		
										TOTAL	1890	1.00
SHORES UNDER THE SLAB AT LEVEL II												
OPER	TIME											
A-11	0	1385	1535	2515	2240	2315	2205	1600	1605		1925	1.02
B-9	1	1115	1260	2040	1805	1850	1795	1365	1160		1550	0.82
A-12	5	2230	2470	4025	3515	3710	3565	2540	2425		3060	1.62
B-10	6	1330	1460	2390	2100	2185	2105	1510	1435		1814	0.96
A-13	8	2155	2445	3880	3420	3555	3450	2515	2335		2969	1.57
SHORES UNDER THE SLAB AT LEVEL 12												
A-12	0	1425	1600	2595	2275	2340	2285	1630	1550		1965	1.04
B-10	1	1100	1235	2020	1760	1835	1755	1280	1225		1526	0.81
A-13	3	2215	2575	4080	3565	3715	3600	2615	2395		3095	1.64
SHORES UNDER THE SLAB AT LEVEL 13												
A-13	0	1345	1565	2535	2215	2280	2200	1595	1495		1905	1.01

MEASUREMENT OF LOADS ON THE FORM-WORK

UNDER THE SLABS AT LEVELS II, 12 & 13

APARTMENT BUILDING AT ALTA-VISTA DR. OTTAWA

FIG NO 26

SHORES (CALCULATED LOADS IN LBS.)

POSTS		1	2	3	4	5	6	7	8	9	AVE.	LR
		1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	
FORM-WORK 10% OF THE SLAB LOAD											120	
											TOTAL	1320 1-00
OPER. TIME MEASURED LOADS ON SHORES IN LBS.												
A-19	0	1305	1265	1280	1325	1370	1320	1280	1285	1325	1310	0-99
B-17	3	1070	1020	1095	1125	1165	1115	1090	1095	1085	1095	0-83
A-20	8	1810	1875	1890	1965	2245	1985	1930	1890	1990	1953	1-48
B-18	11	1125	1105	1110	1230	1185	1275	1100	1165	1160	1162	0-88
A-21	14	1430	1485	1450	1495	1530	1515	1480	1495	1430	1478	1-12

MEASUREMENT OF LOADS ON THE FORM-WORK

UNDER THE SLAB AT LEVEL 19

PLACE DU PORTAGE, HULL, QUEBEC.

FIG. NO. 48

SHORES (CALCULATED LOADS IN LBS)

POSTS		1	2	3	4	5	6	7	8	9	AVE	L.R.
		1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	
FORM-WORK 10% OF THE SLAB LOAD.											120	
(MEASURED LOADS IN LBS)											TOTAL	1320 100
OPER. TIME SHORES UNDER THE SLAB AT LEVEL 20												
A-20	0	1310	1305	1330	1405	1385	1335	1295	1275	1360	1335	1-01
B-18	3	1010	1030	1065	1125	1165	1050	1015	1030	905	1045	0-79
A-21	6	1875	1890	1905	1945	2035	1920	1910	1890	1730	1900	1-44
B-19	9	1100	1130	1105	1165	1230	1135	1140	1115	980	1125	0-85
A-22	12	1425	1470	1455	1465	1510	1505	1455	1485	1425	1466	1-11
SHORES UNDER THE SLAB AT LEVEL 21												
A-21	0	1325	1300	1310	1385	1375	1405	1350	1300	1355	1345	1-02
B-19	3	990	980	1015	1085	1100	1030	1015	995	940	1015	0-77
A-22	6	1865	1880	1925	1995	2070	1935	1925	1895	1740	1914	1-45
SHORES UNDER THE SLAB AT LEVEL 22												
A-22	0	1320	1290	1305	1370	1400	1410	1335	1310	1350	1343	1-02

MEASUREMENT OF LOADS ON THE FORM-WORK
 UNDER THE SLABS AT LEVELS 20, 21 & 22
 PLACE DU PORTAGE, HULL, QUEBEC.

FIG. NO.49

APPENDIX 5

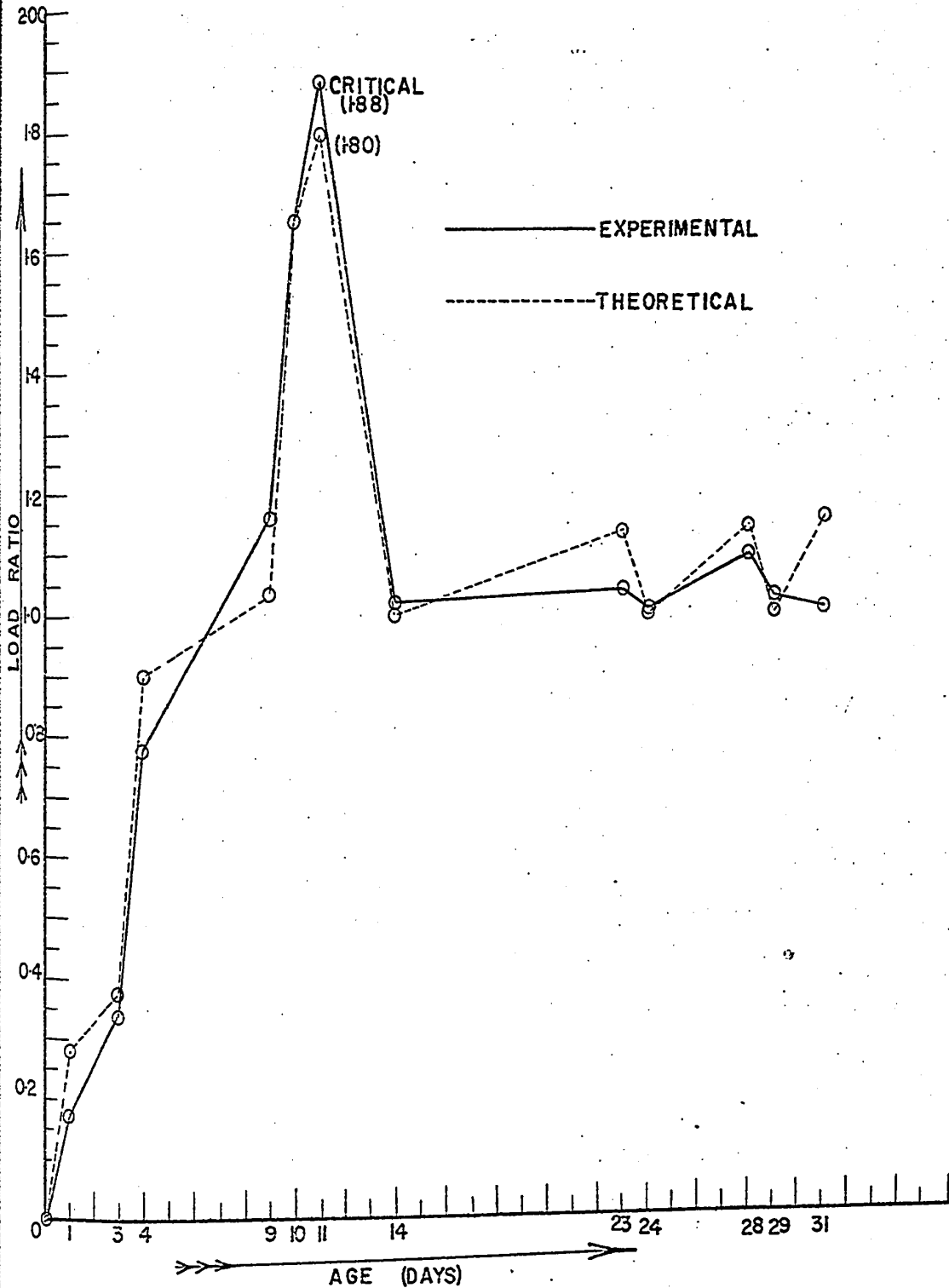
Graphical representation of the load ratio (actual and theoretical) apply to adjacent components (slabs and shores-reshores):

A. Apartment Building at Alta Vista Drive, Ottawa

- 1) For slabs see Figures 32. to 37
- 2) For shores-reshores see Figures 38 to 43

B. "Place Du Portage" in Hull, Quebec

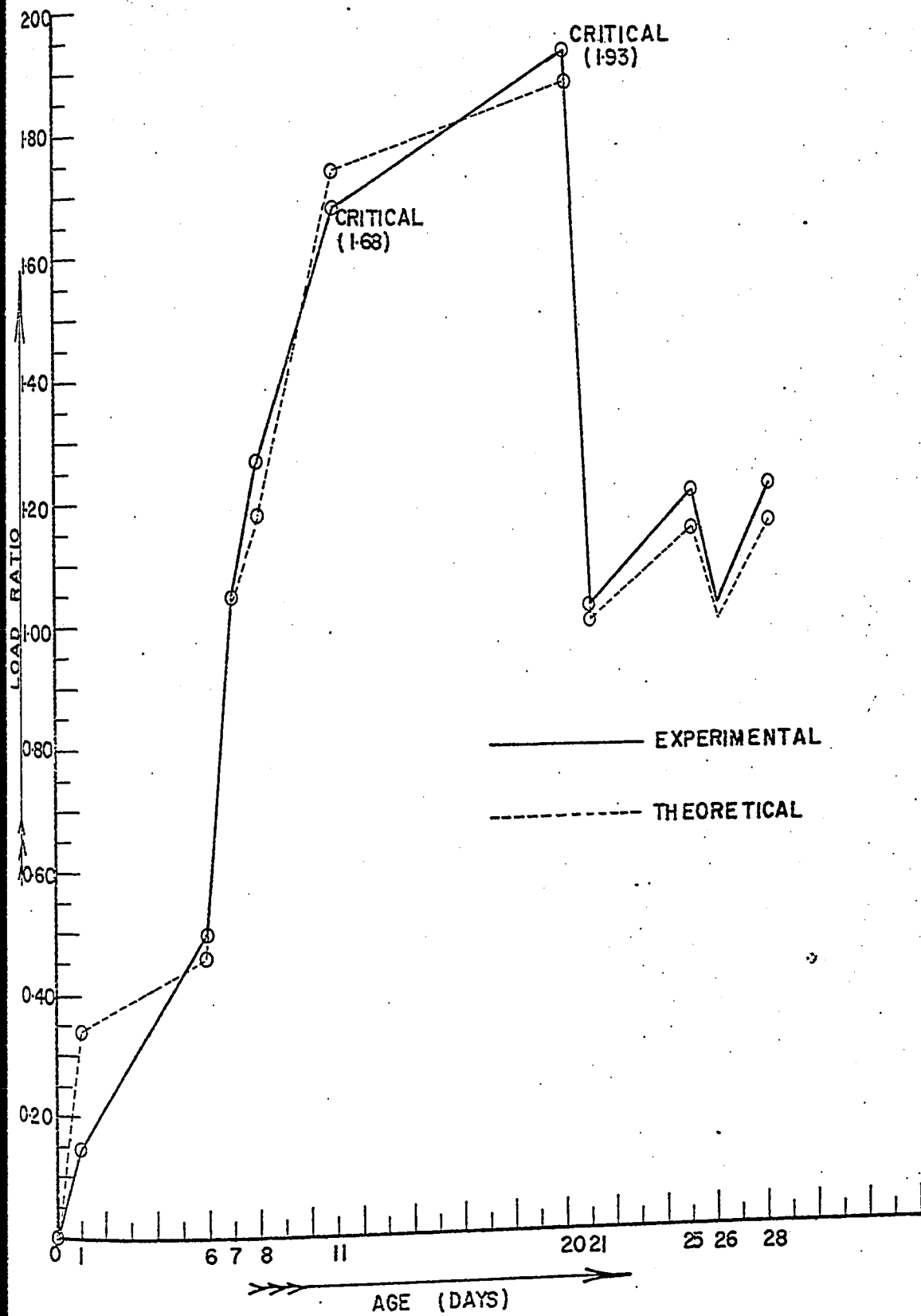
- 1) For slabs see Figures 53 to 55
- 2) For shores see Figures 56 to 58



LOAD RATIOS APPLY TO SLAB AT LEVEL 7.

APARTMENT BUILDING AT ALTA-VISTA DR, OTTAWA

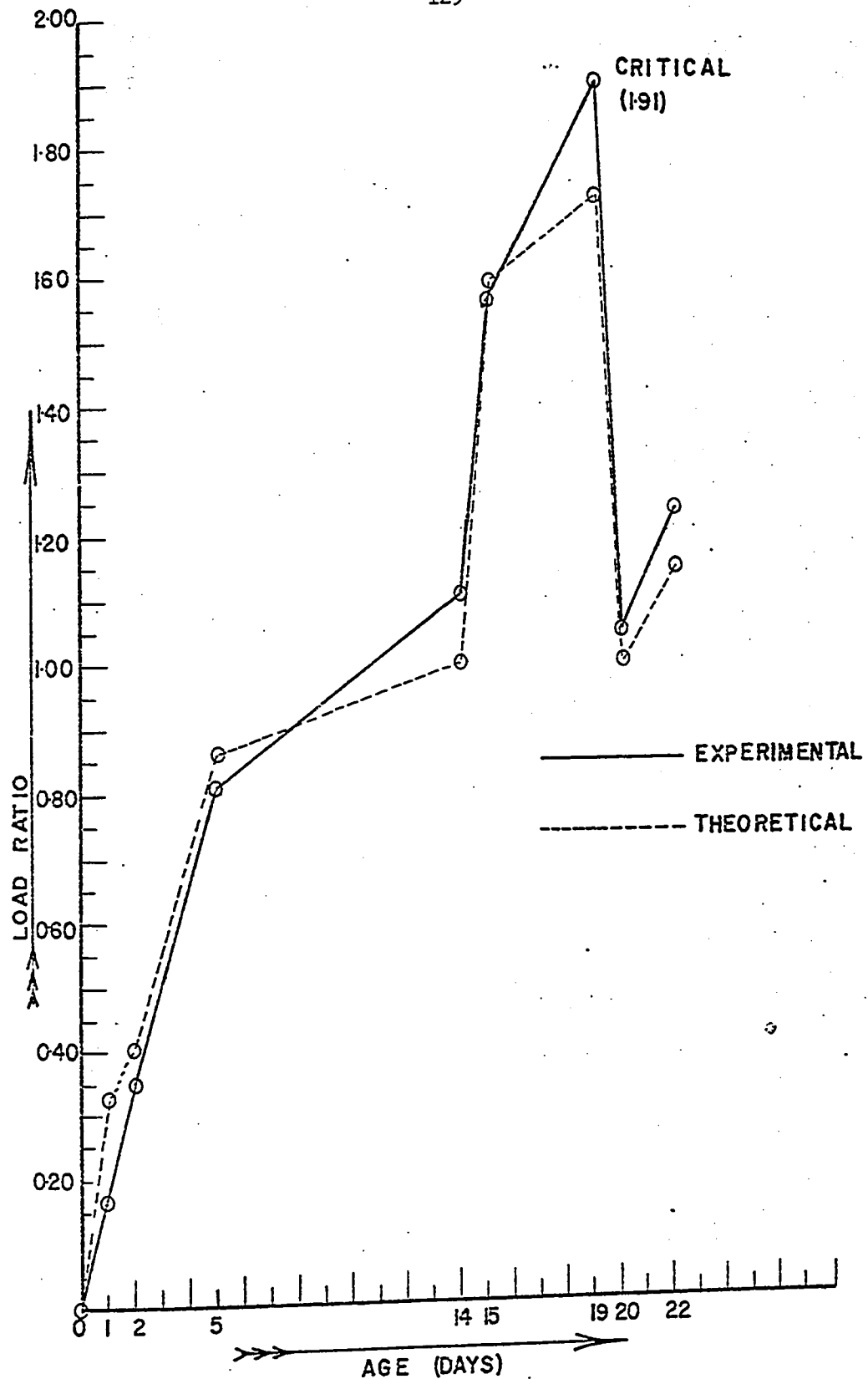
FIG NO-32



LOAD RATIOS APPLY TO SLAB AT LEVEL 8.

APARTMENT BUILDING AT ALTA-VISTA DR, OTTAWA.

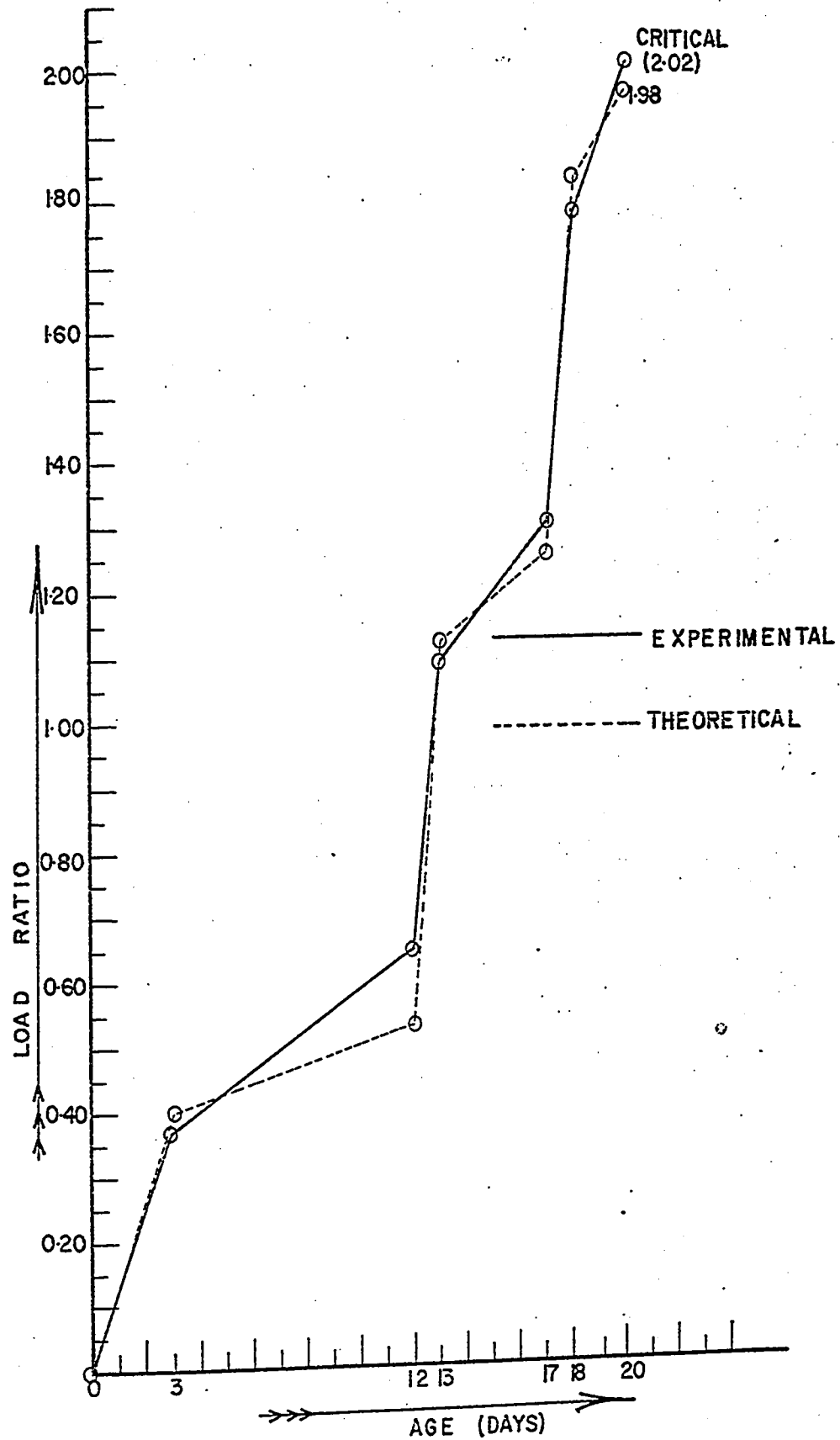
FIG-NO-33



LOAD RATIOS APPLY TO SLAB AT LEVEL 9.

APARTMENT BUILDING AT ALTA-VISTA DR, OTTAWA

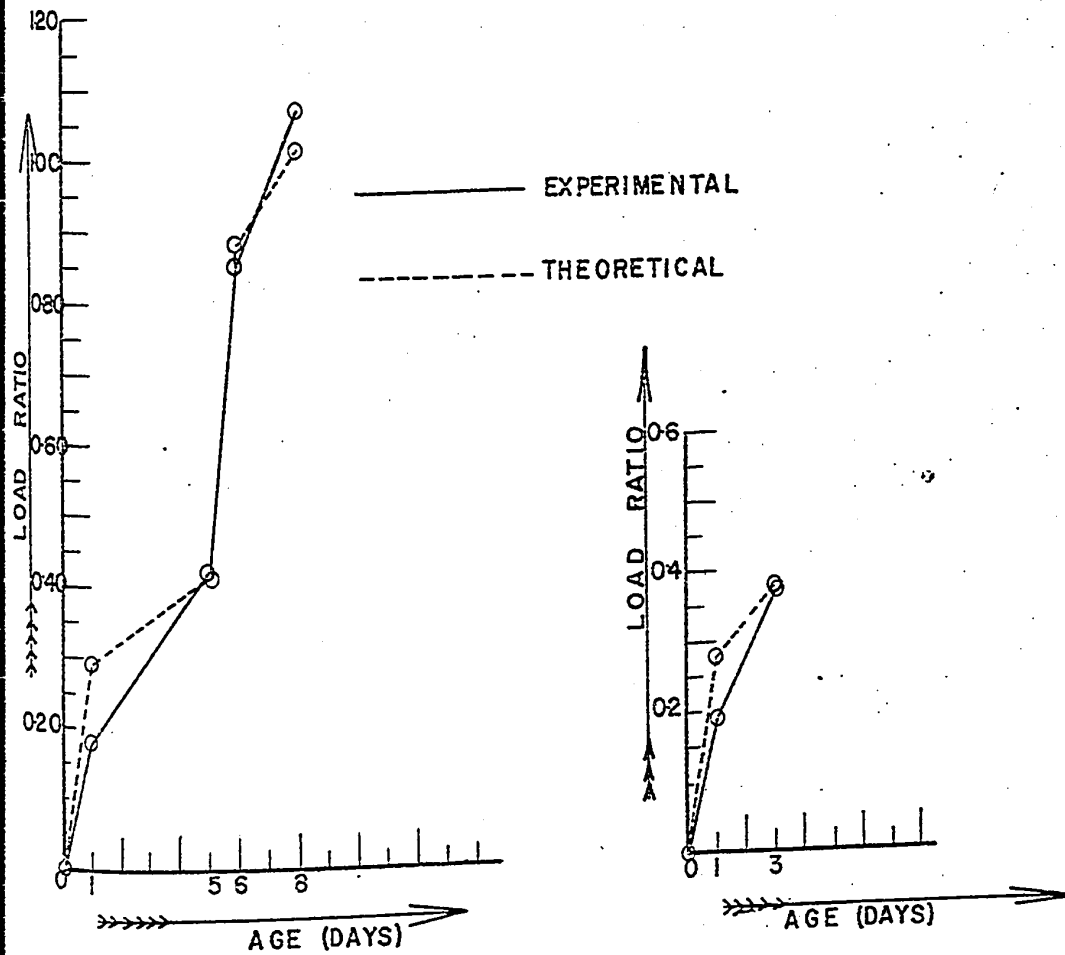
FIG-NO-34



LOAD RATIOS APPLY TO SLAB AT LEVEL 10.

APARTMENT BUILDING AT ALTA-VISTA DR, OTTAWA.

FIG. NO-35

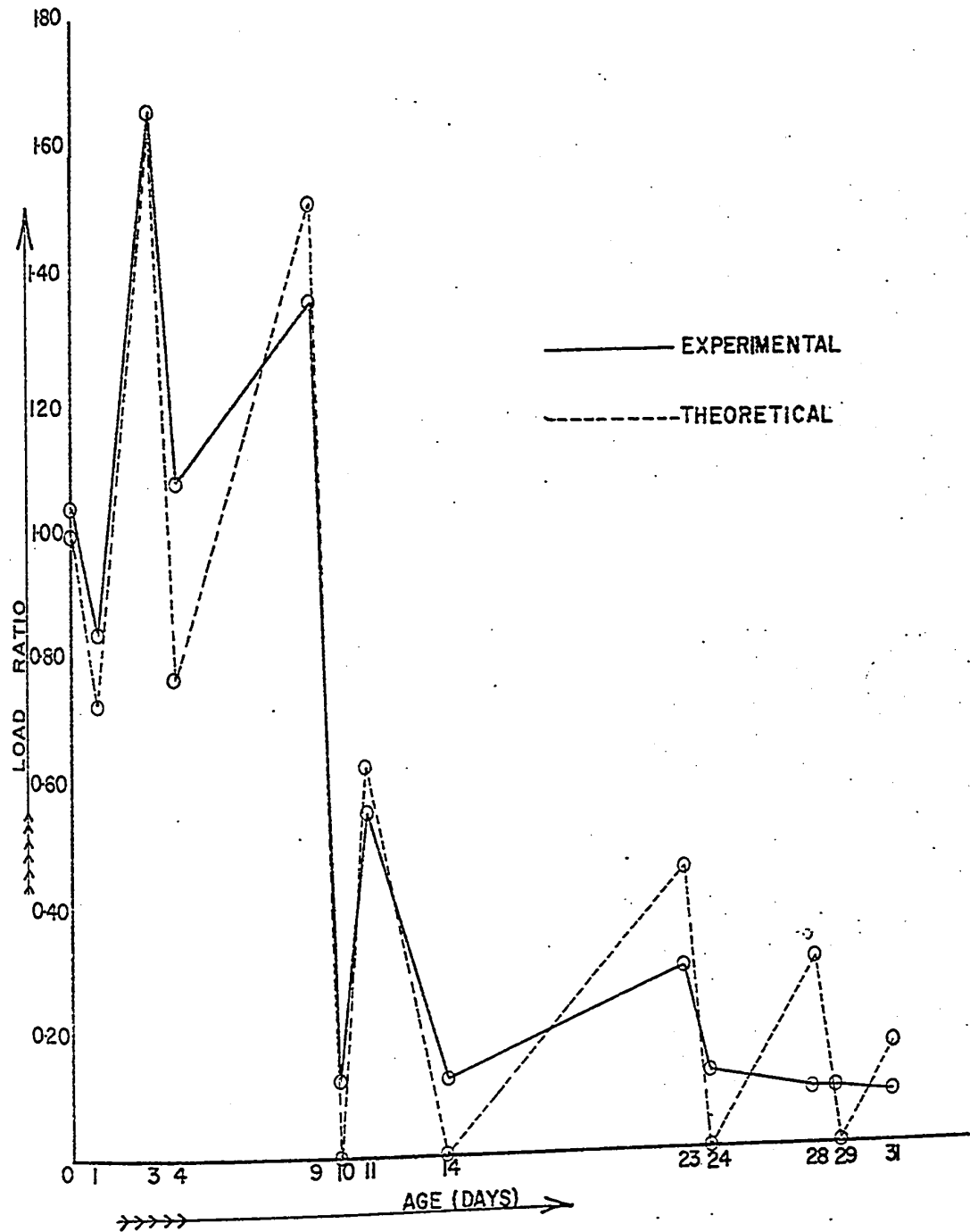


LOAD RATIOS APPLY TO SLABS

AT LEVEL 11
 AT LEVEL 12
 APARTMENT BUILDING AT ALTA-VISTA DR; OTTAWA

FIG-NO-36

FIG-NO-37

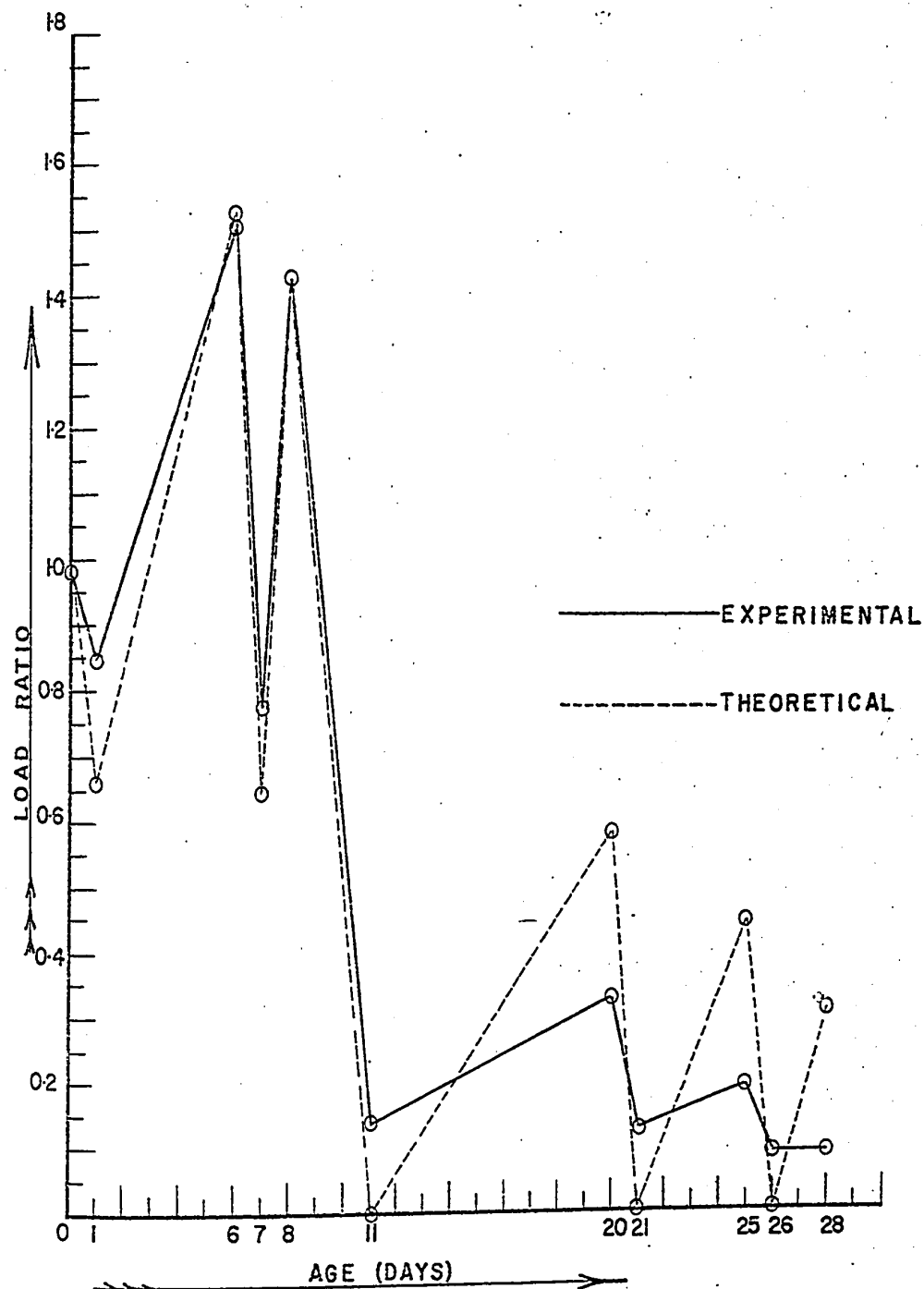


LOAD RATIOS APPLY TO SHORES & RESHORES

UNDER THE SLAB AT LEVEL 7.

APARTMENT BUILDING AT ALTA-VISTA DR., OTTAWA

FIG.NO.38

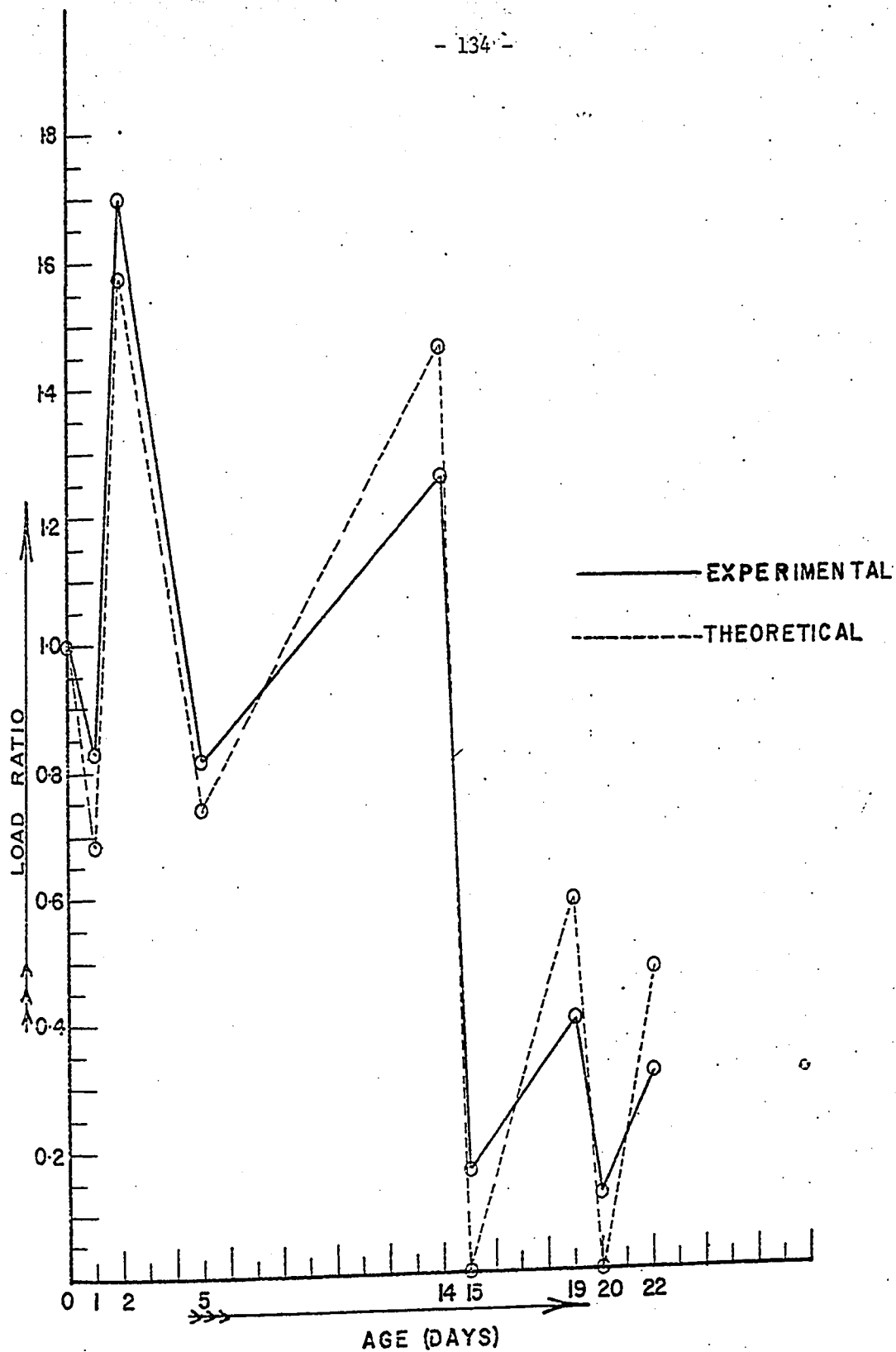


LOAD RATIOS APPLY TO SHORES & RESHORES

UNDER THE SLAB AT LEVEL 8.

APARTMENT BUILDING AT ALTA-VISTA DR; OTTAWA

FIG. NO-39

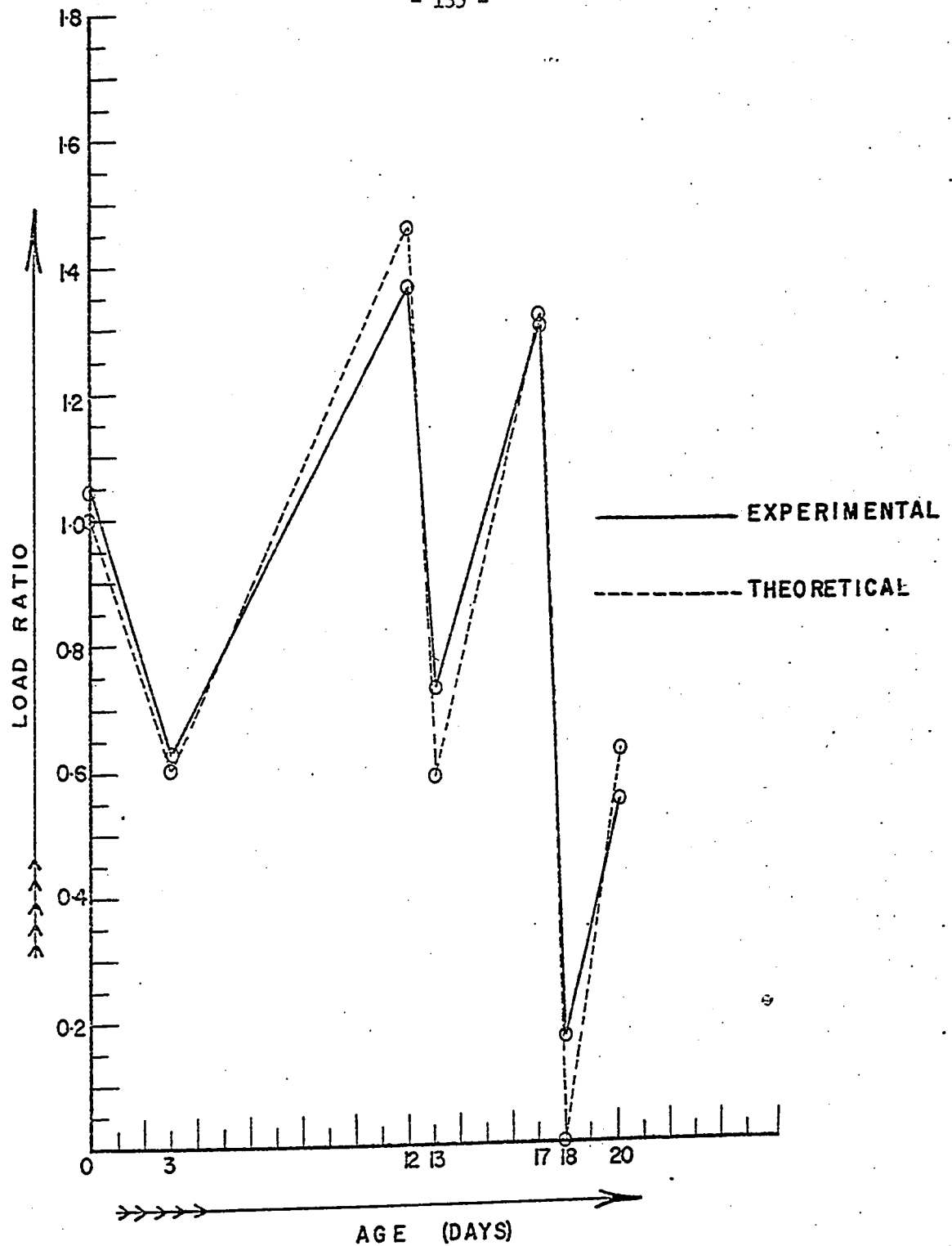


LOAD RATIOS APPLY TO SHORES & RESHORES

UNDER THE SLAB AT LEVEL 9.

APARTMENT BUILDING AT ALTA-VISTA DR; OTTAWA

FIG-NO-40



LOAD RATIOS APPLY TO SHORES & RESHORES

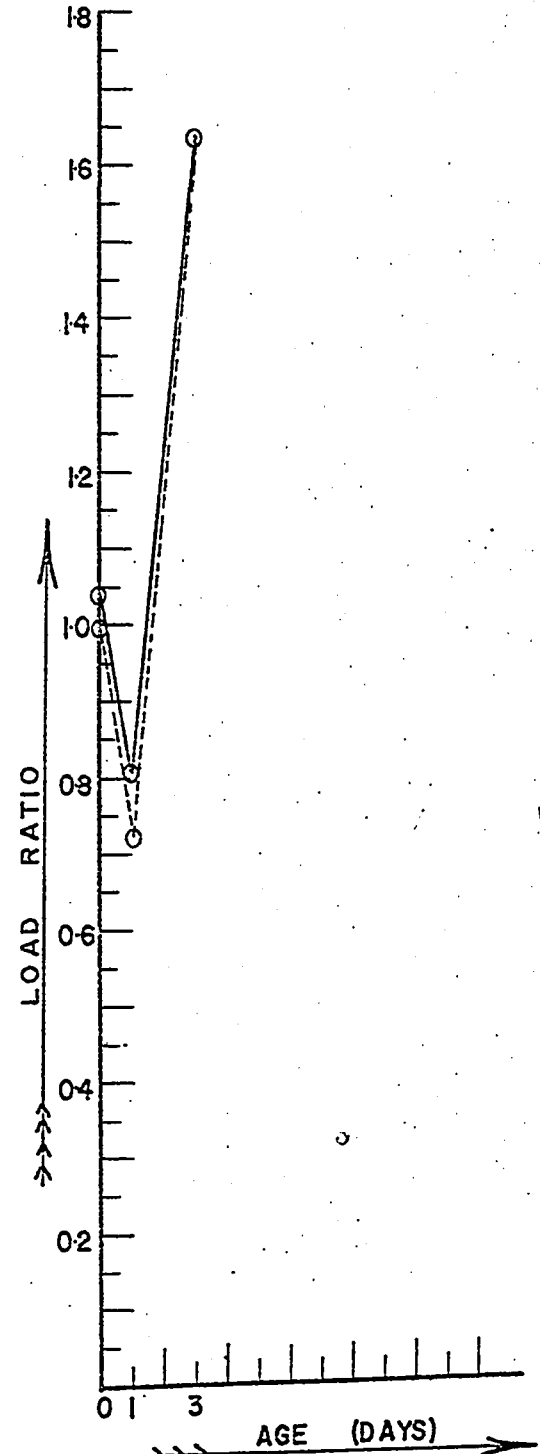
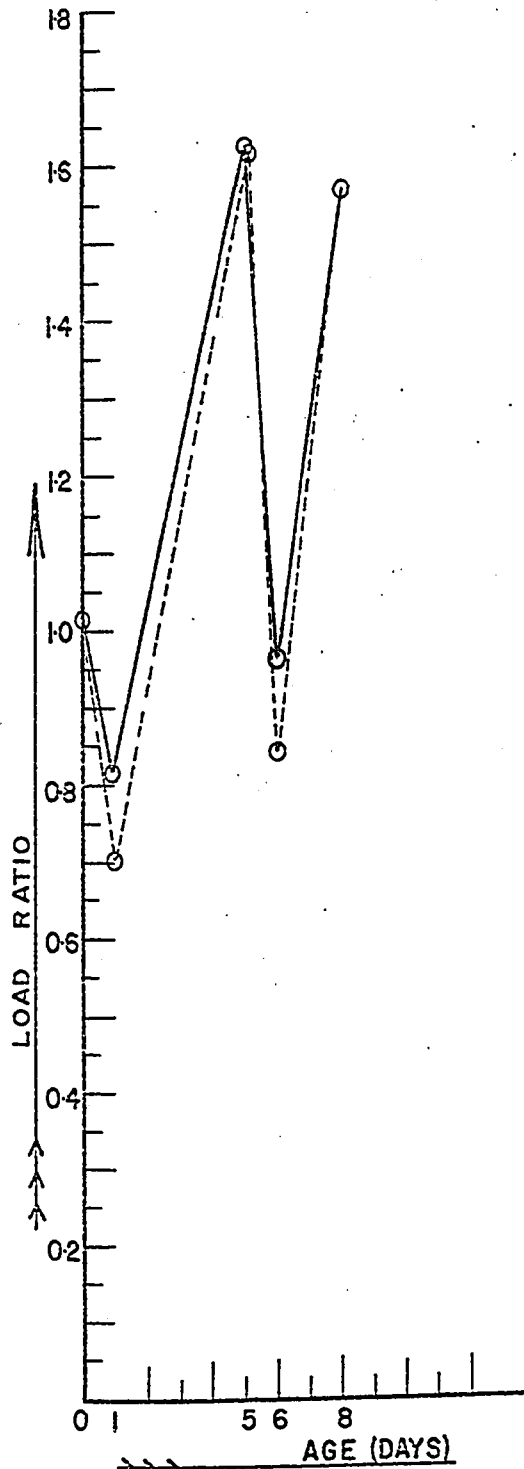
UNDER THE SLAB AT LEVEL 10

APARTMENT BUILDING AT ALTA-VISTA DR; OTTAWA

FIG. NO 41

EXPERIMENTAL

THEORETICAL



LOAD RATIOS APPLY TO SHORES & RESHORES

UNDER THE SLABS

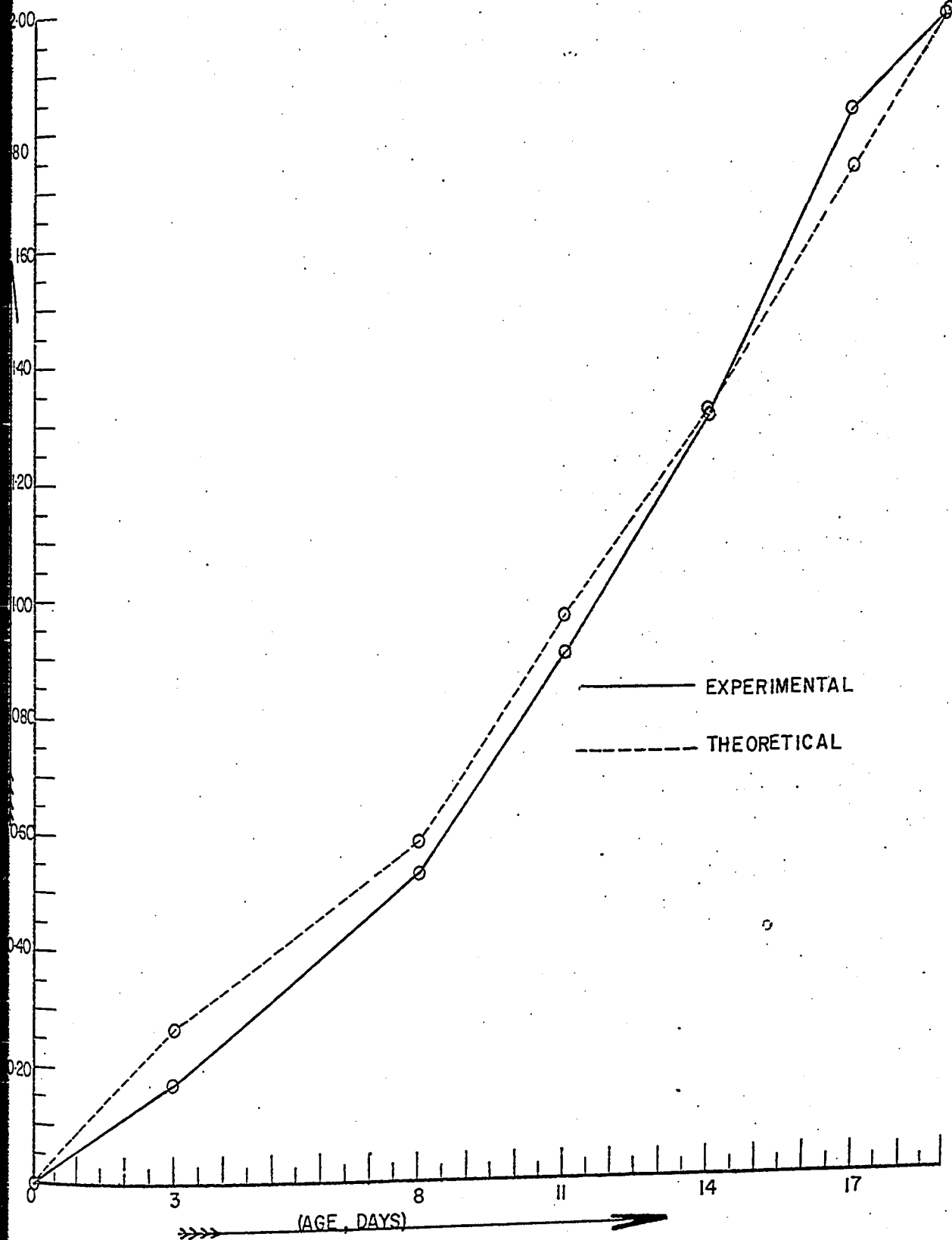
AT LEVEL II.

AT LEVEL 12.

APARTMENT BUILDING AT ALTA-VISTA DR; OTTAWA

FIG-NO-42

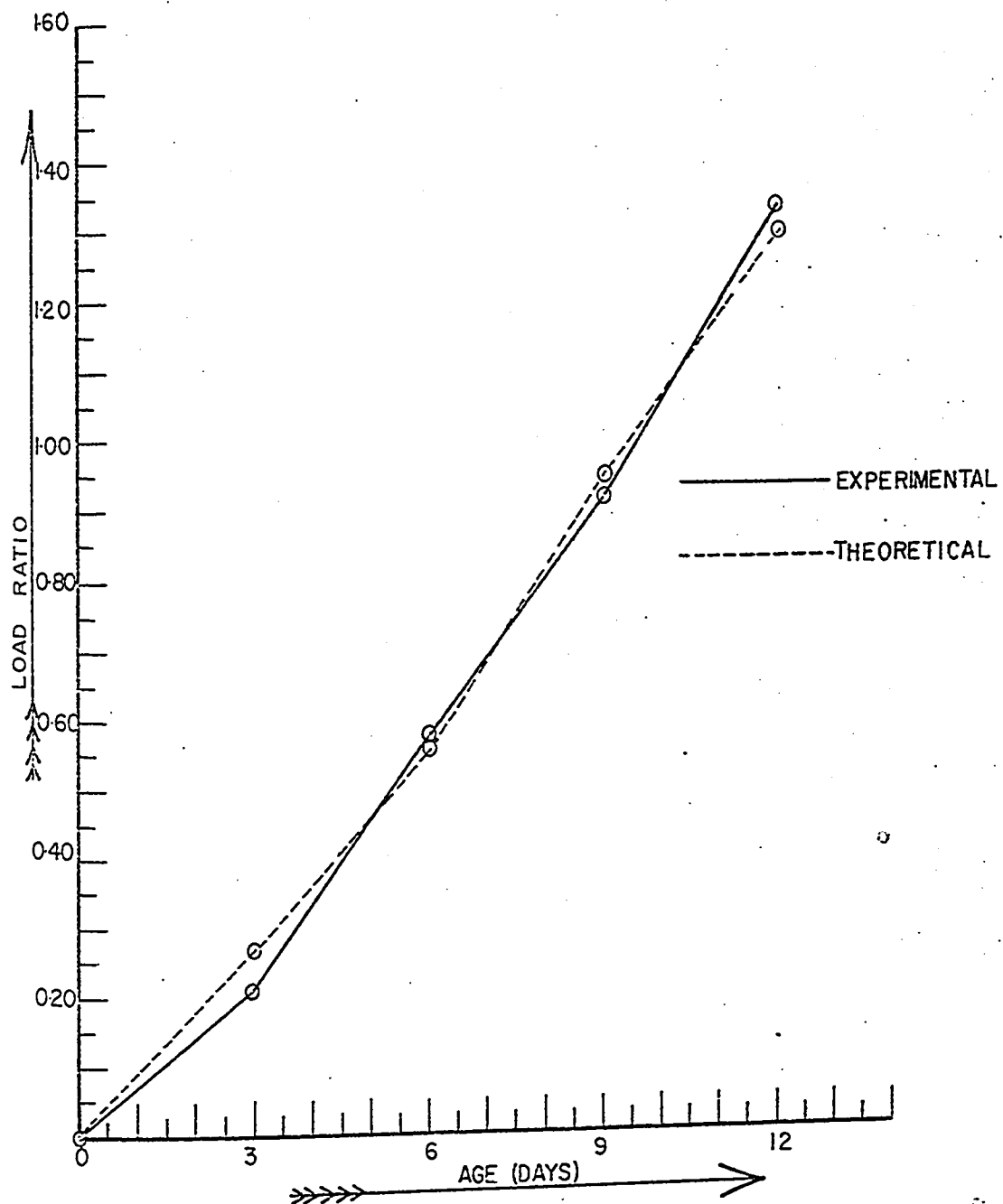
FIG-NO-43



LOAD RATIOS APPLY TO SLAB AT LEVEL 19.

PLACE DU PORTAGE, HULL.

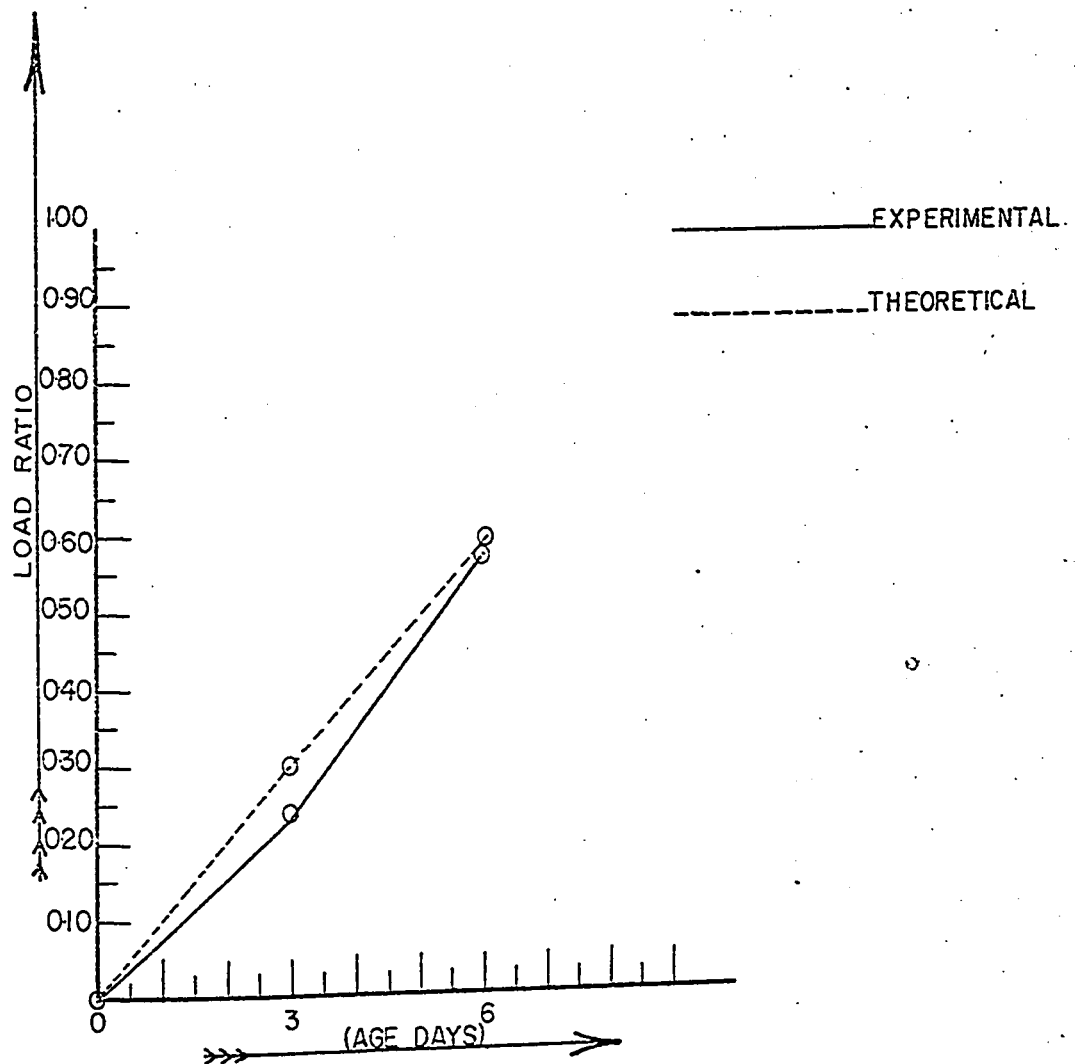
FIG. NO. 53



LOAD RATIOS APPLY TO SLAB AT LEVEL 20.

PLACE DU PORTAGE, HULL.

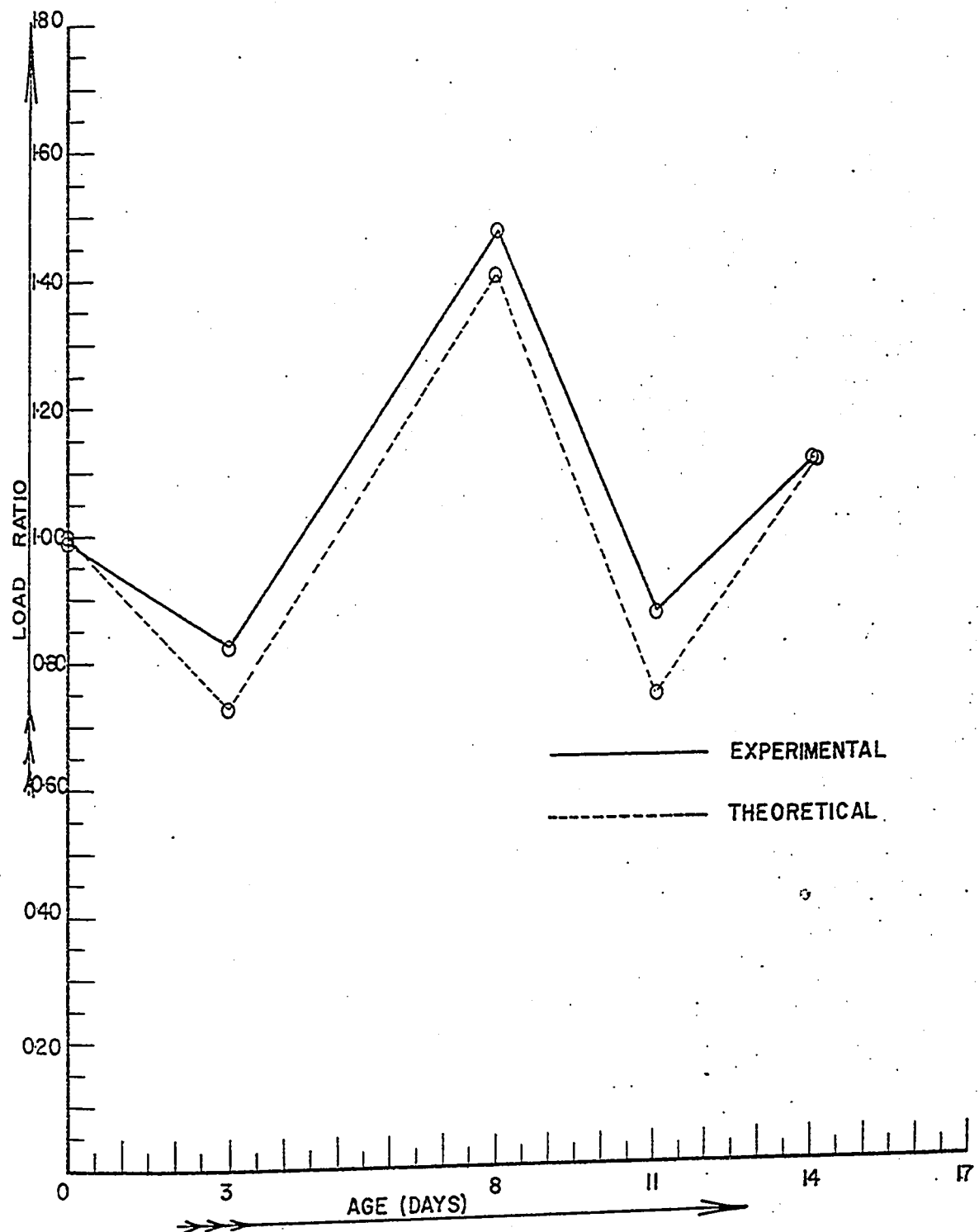
FIG. NO-54



LOAD RATIOS APPLY TO SLAB AT LEVEL 21.

PLACE DU PORTAGE, HULL.

FIG. NO-55

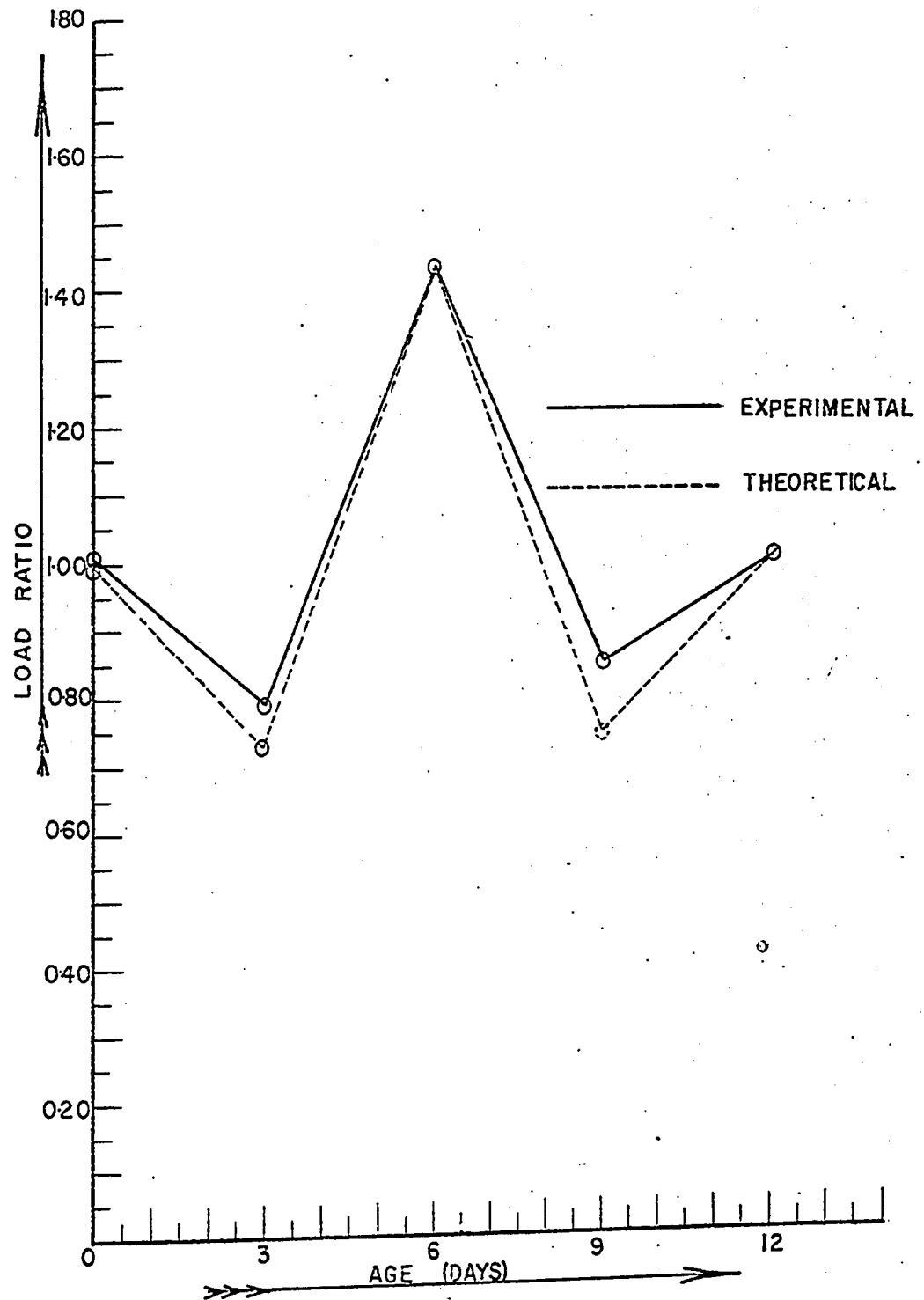


LOAD RATIOS APPLY TO SHORES UNDER

THE SLAB AT LEVEL 19.

PLACE DU PORTAGE, HULL.

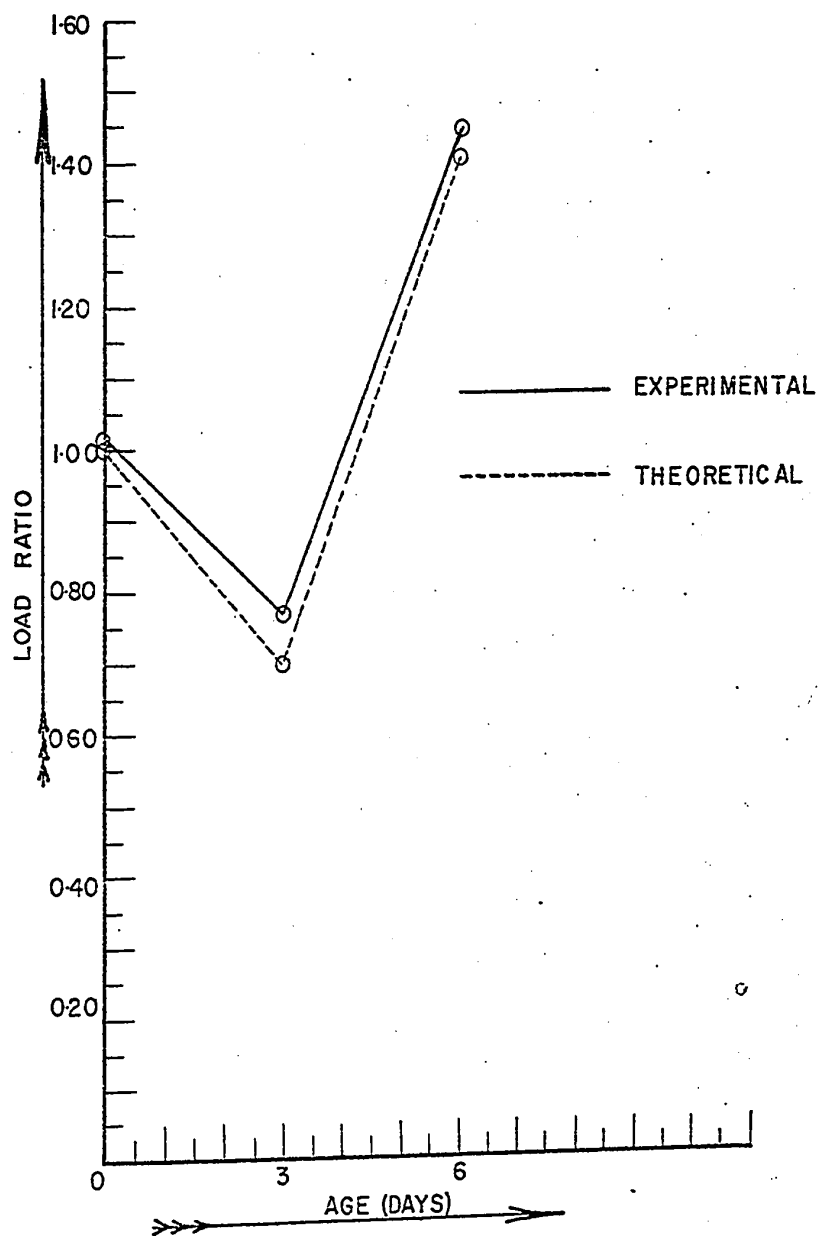
FIG. NO. 56



LOAD RATIOS APPLY TO SHORES UNDER
THE SLAB AT LEVEL 20.

PLACE DU PORTAGE, HULL.

FIG. NO. 57



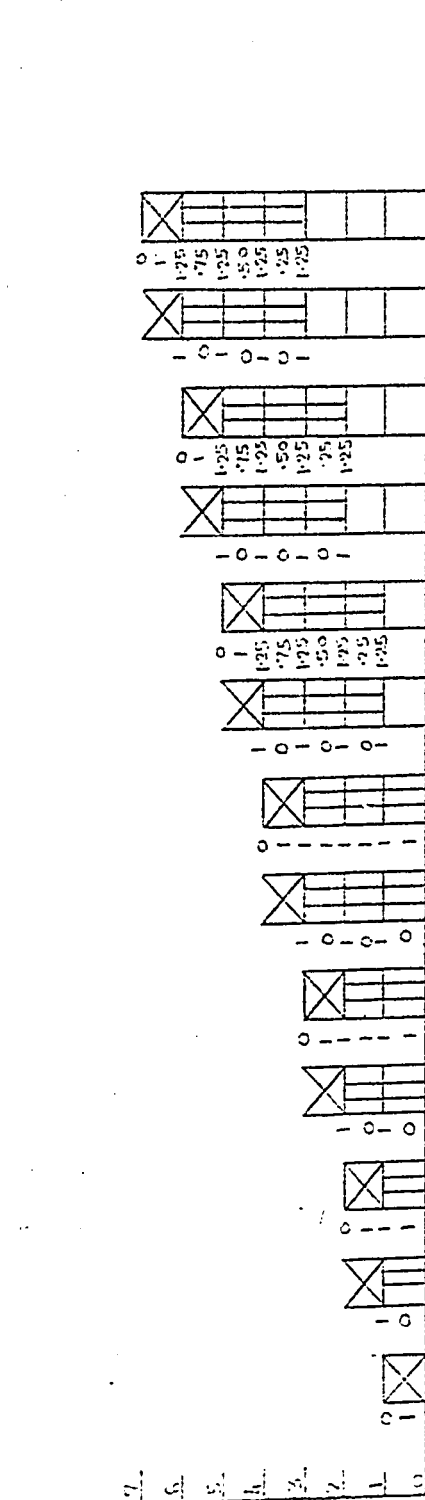
LOAD RATIOS APPLY TO SHORES UNDER
THE SLAB AT LEVEL 21.
PLACE DU PORTAGE, HULL.

FIG. NO 58

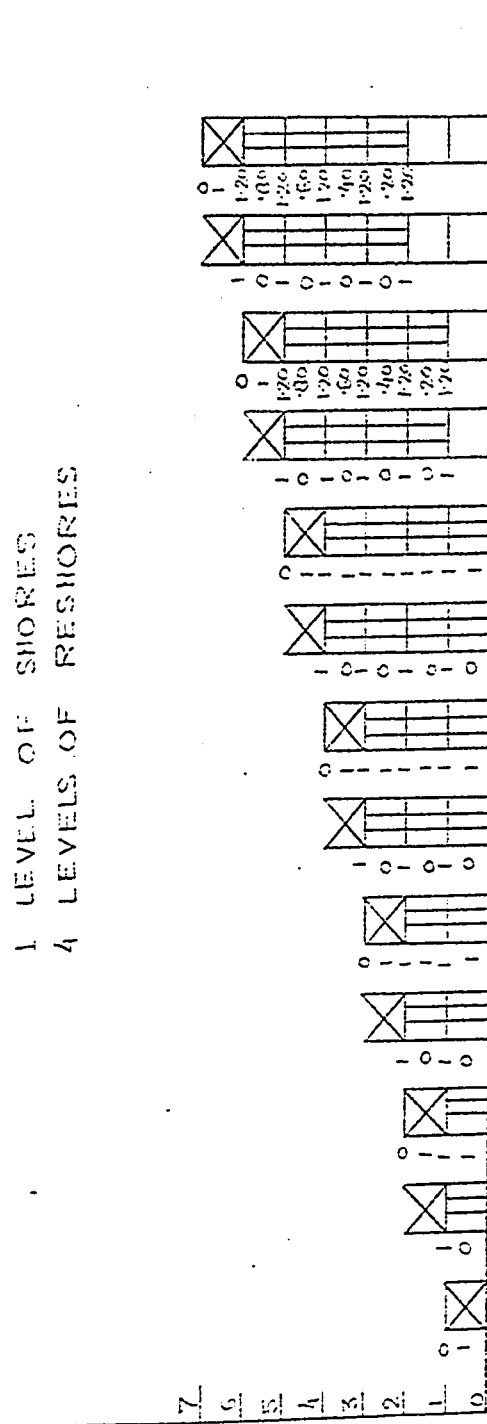
APPENDIX 6

THE DETAILED ANALYSIS FOR VARIOUS SHORE/RESHORE COMBINATION
WITH CONSTANT E_c .

1 LEVEL OF SHORES

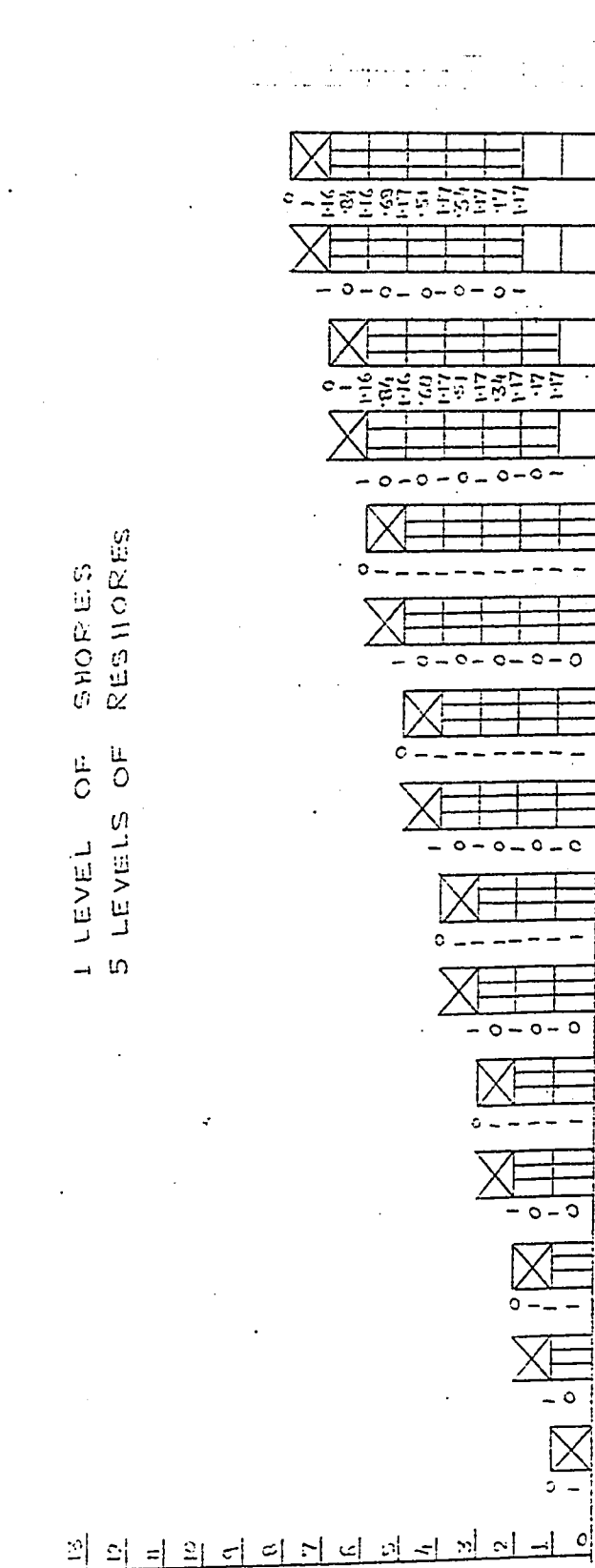


ABSOLUTE MAX. L.R. = 1.25
CONVERGED MAX. L.R. = 1.25



ABSOLUTE MAX. L.R.	= 1.20
CONVERGED MAX. L.R.	= 1.20

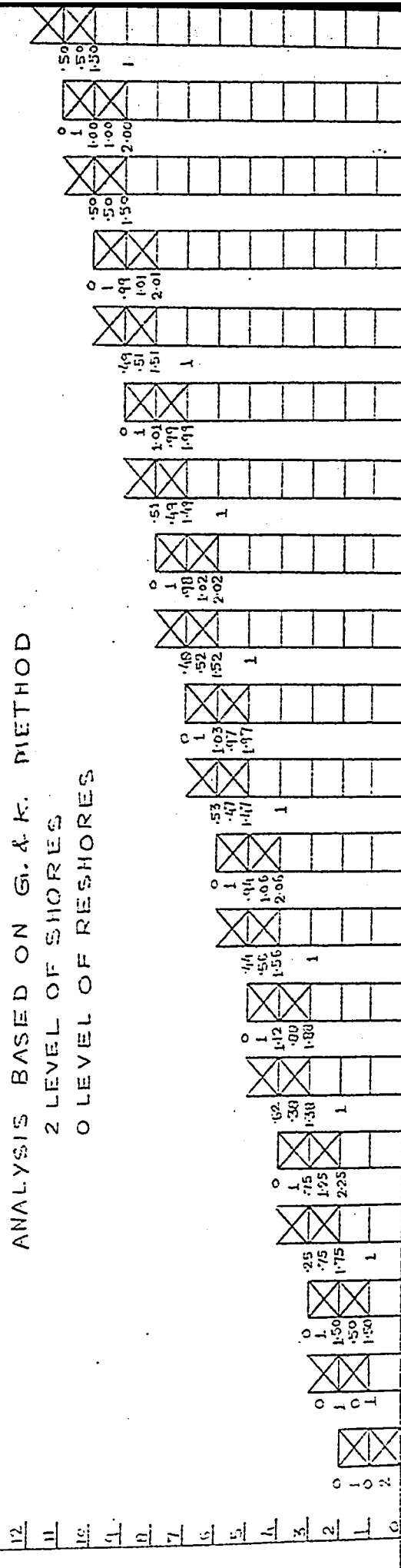
1 LEVEL OF SHORES
5 LEVELS OF RESHOES



ABSOLUTE MAX. L.R. = 1.17
CONVERGED MAX. L.R. = 1.17

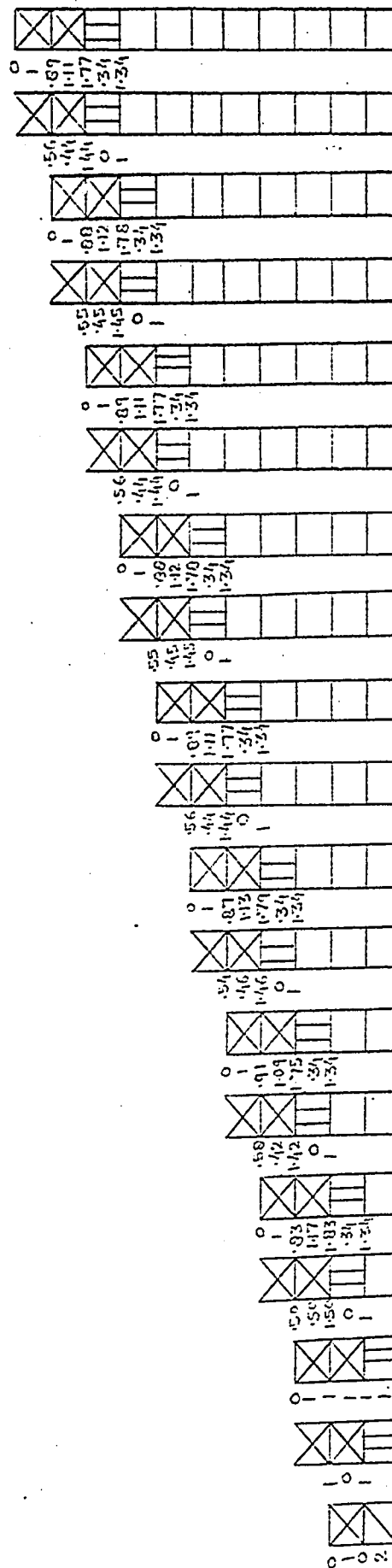
L.R. APPLY TO ADJACENT COMPONENTS
(PROPS & SLABS)

ANALYSIS BASED ON G. & K. METHOD
2 LEVEL OF SHORES
0 LEVEL OF RESHORES



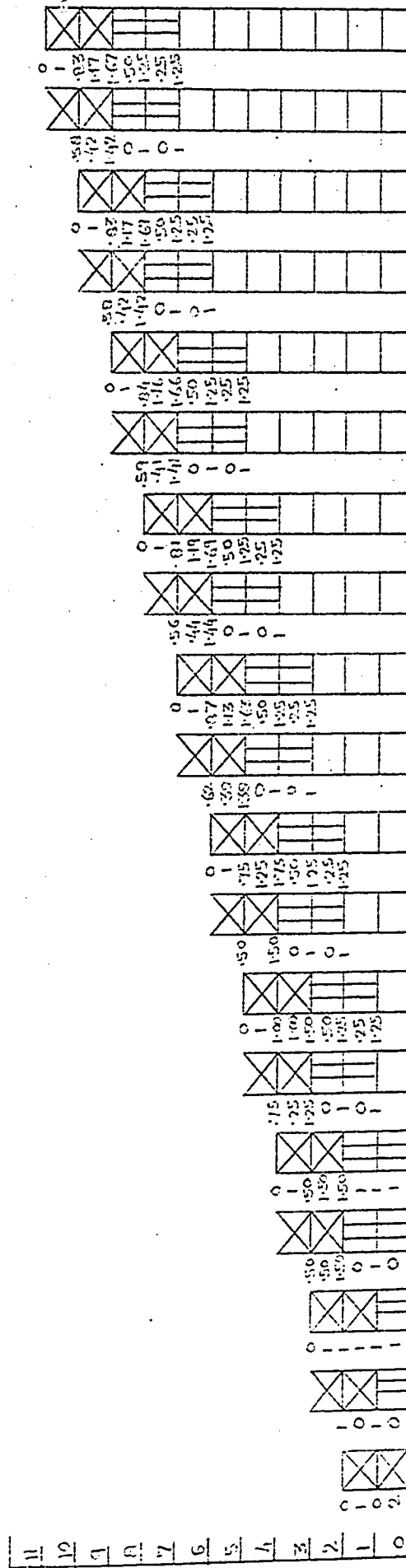
ABSOLUTE MAX. L.R. = 2.25
CONVERGED MAX. L.R. = 2.00.

2 LEVELS OF SHORES
1 LEVEL OF RESHORES

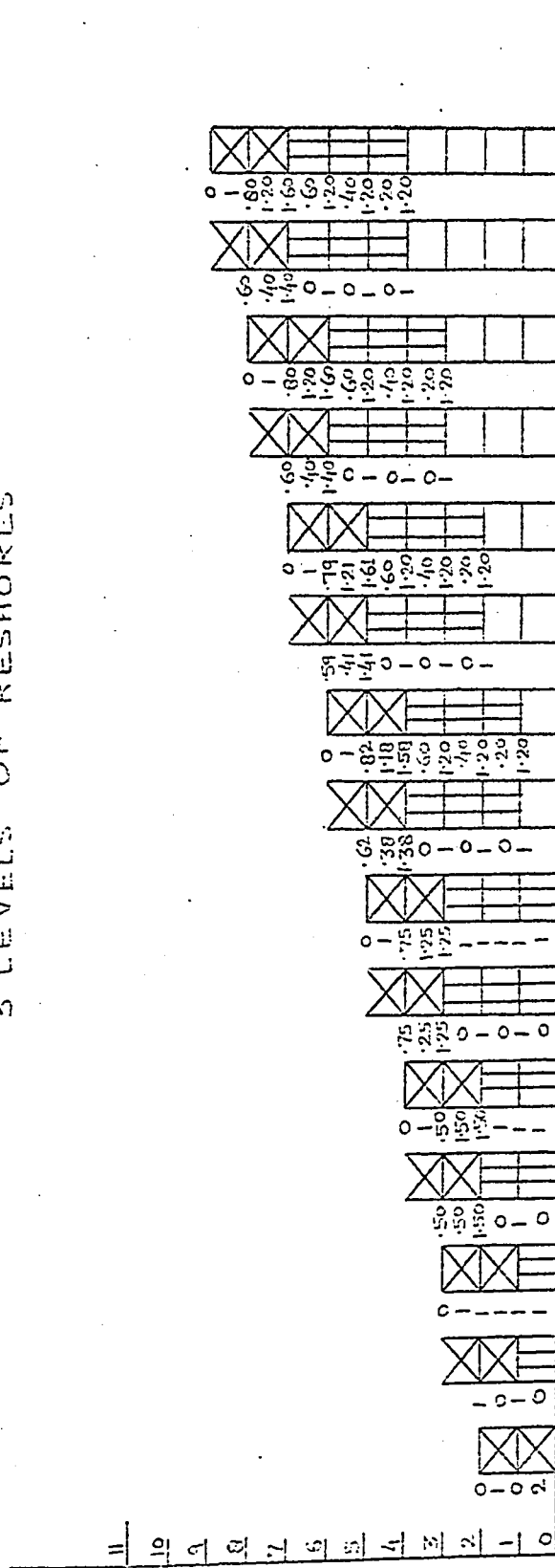


ABSOLUTE MAX. L.R. = 1.83
CONVERGED MAX. L.R. = 1.77 (< 2)

2. LEVELS OF SHOLES
2. LEVELS OF RISHOLES

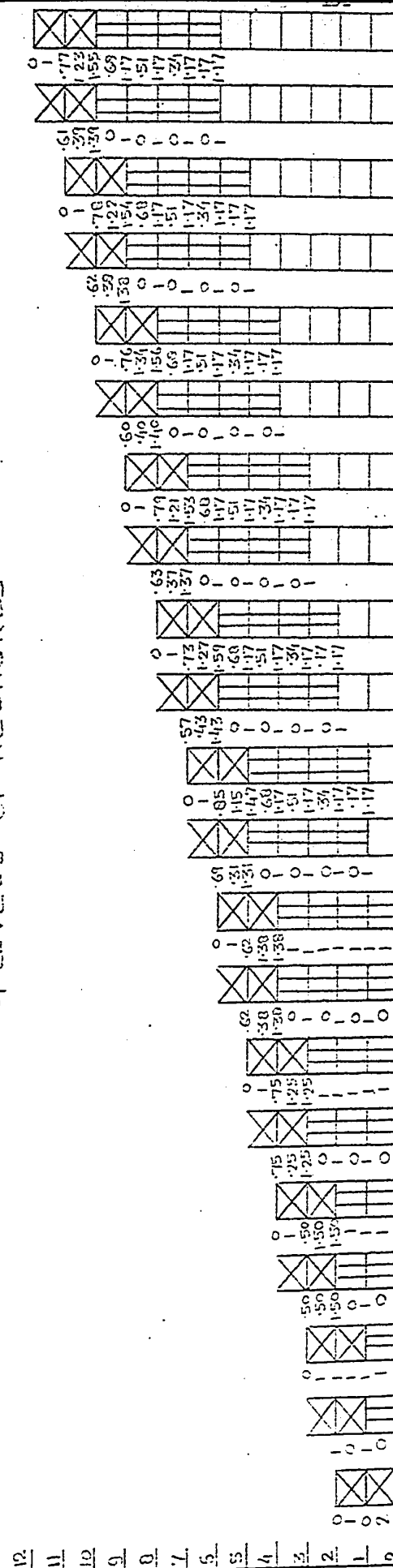


ABSOLUTE MAX. L.R. = 1.75
CONVERGED MAX. L.R. = 1.67

2 LEVELS OF SHORES
3 LEVELS OF RESHORES

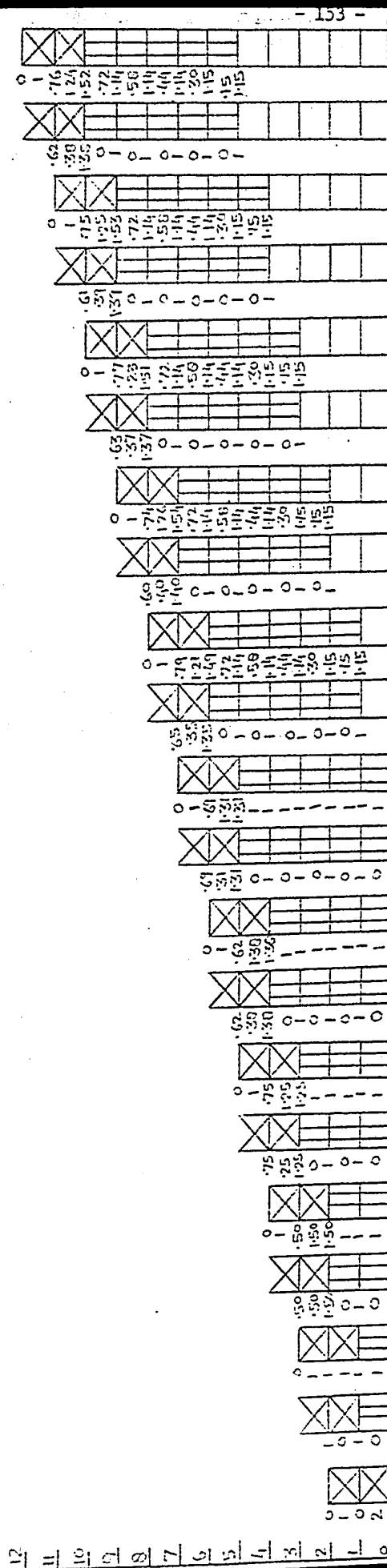
ABSOLUTE	MAX.	L. R.	= 1.61
CONVERGED	MAX.	L. R.	= 1.60

2 LEVELS OF SHORES
4 LEVELS OF RESHORES



ABSOLUTE MAX. L.R. = 159
CONVERGED MAX. L.R. = 155

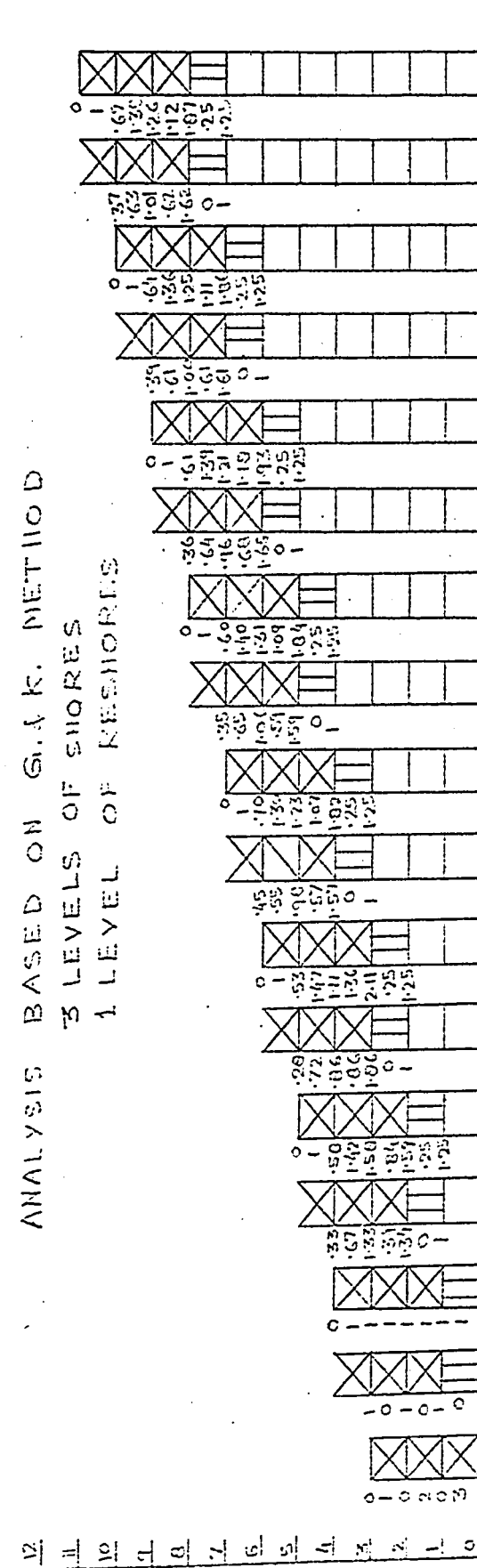
2 LEVELS OF SHORES 5 LEVELS OF RESHORES



ABSOLUTE MAX. L. R. = 1.54
CONVERGED MAX. L. R. = 1.52 (≤ 2)

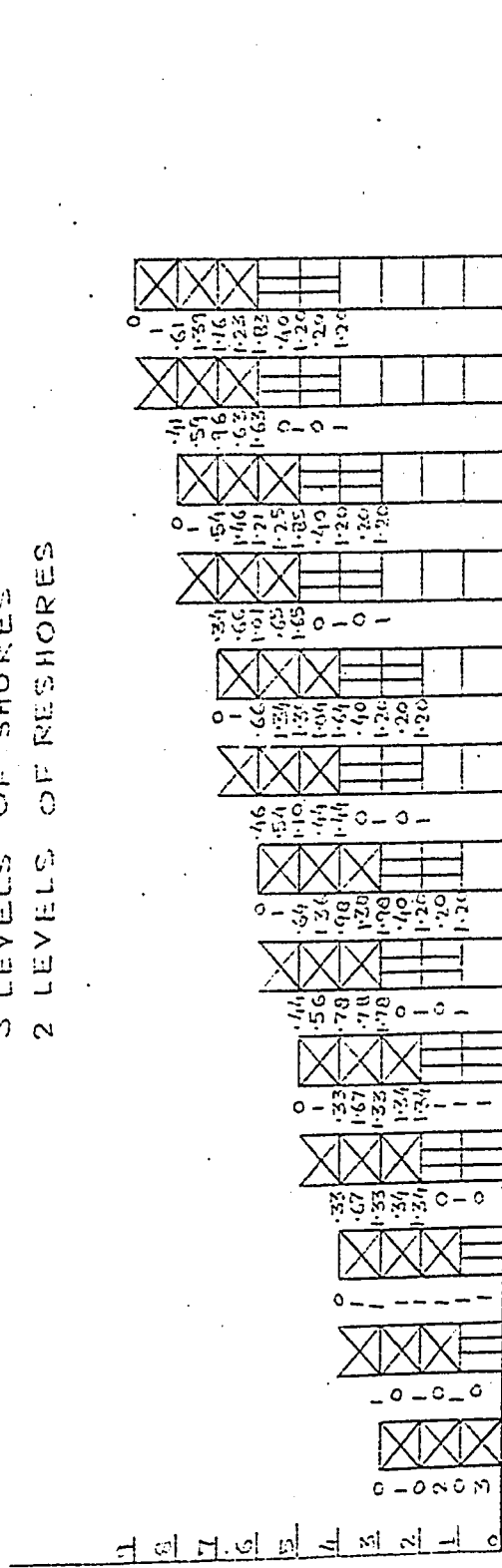
L.R. APPLY TO ADJACENT COMPONENTS
(PROPS & SLABS)

ANALYSIS BASED ON G.A.K. METHOD
3 LEVELS OF SHORES
1 LEVEL OF KESHORES



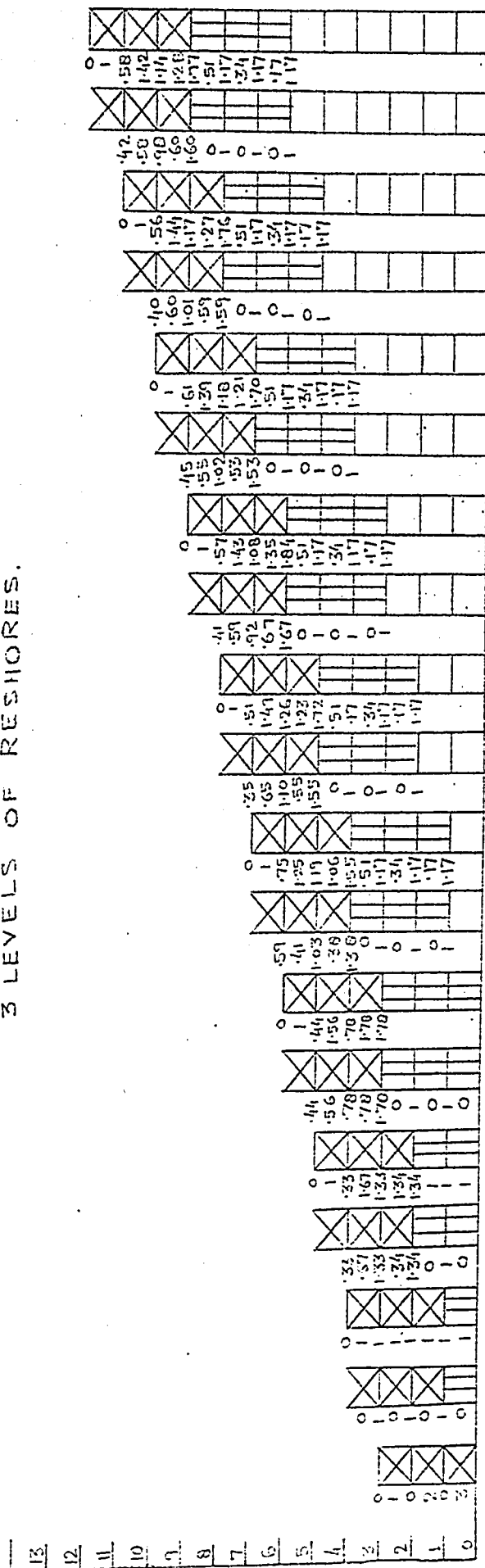
ABSOLUTE MAX. L.R. = 2.11
CONVERSED MAX. L.R. = 1.87 (≤ 2)

3 LEVELS OF SHORES
2 LEVELS OF RESHORES



ABSOLUTE MAX. L.R. = 1.98
CONVERGED MAX. L.R. = 1.83 (< 2)

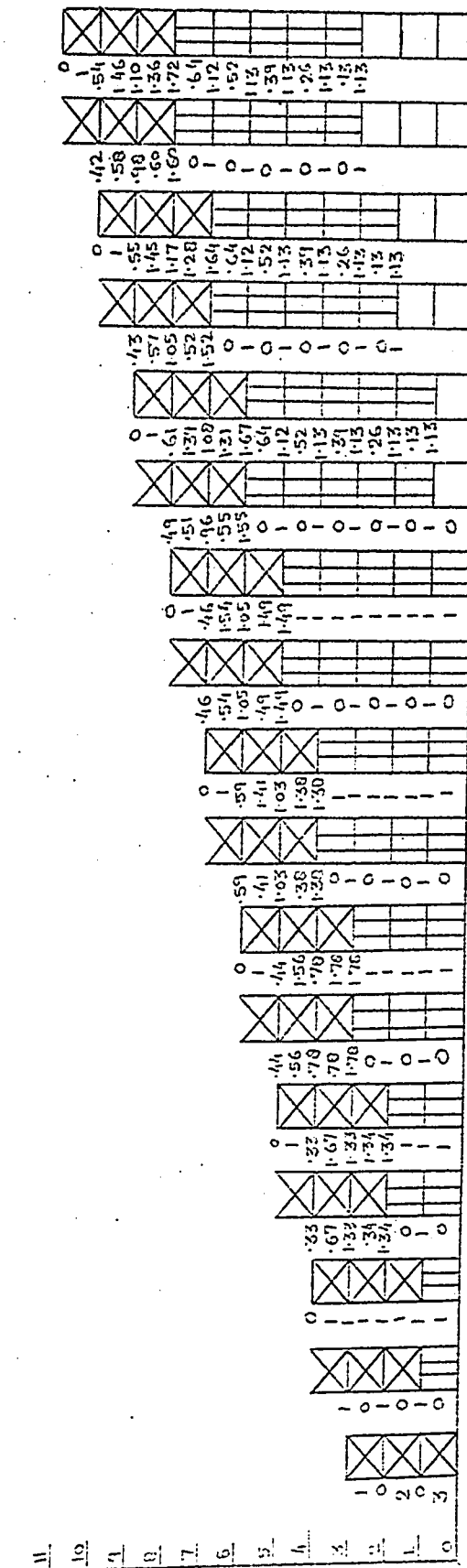
3 LEVELS OF SHORES



ABSOLUTE MAX. L. R. = 1.24

CONVERGED MAX. L.R. = 1.76 (≤ 2)

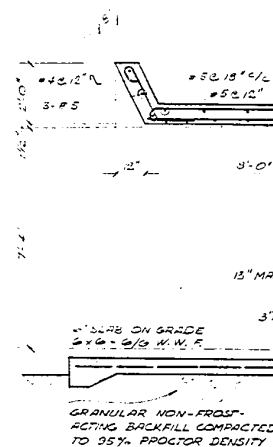
3 LEVELS OF SHORES
5 LEVELS OF RESHORES

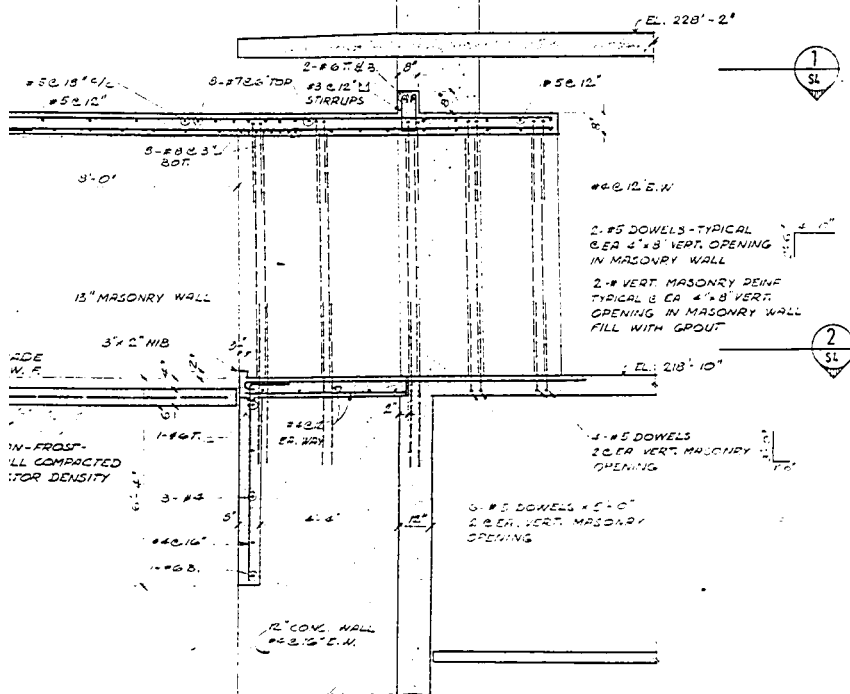
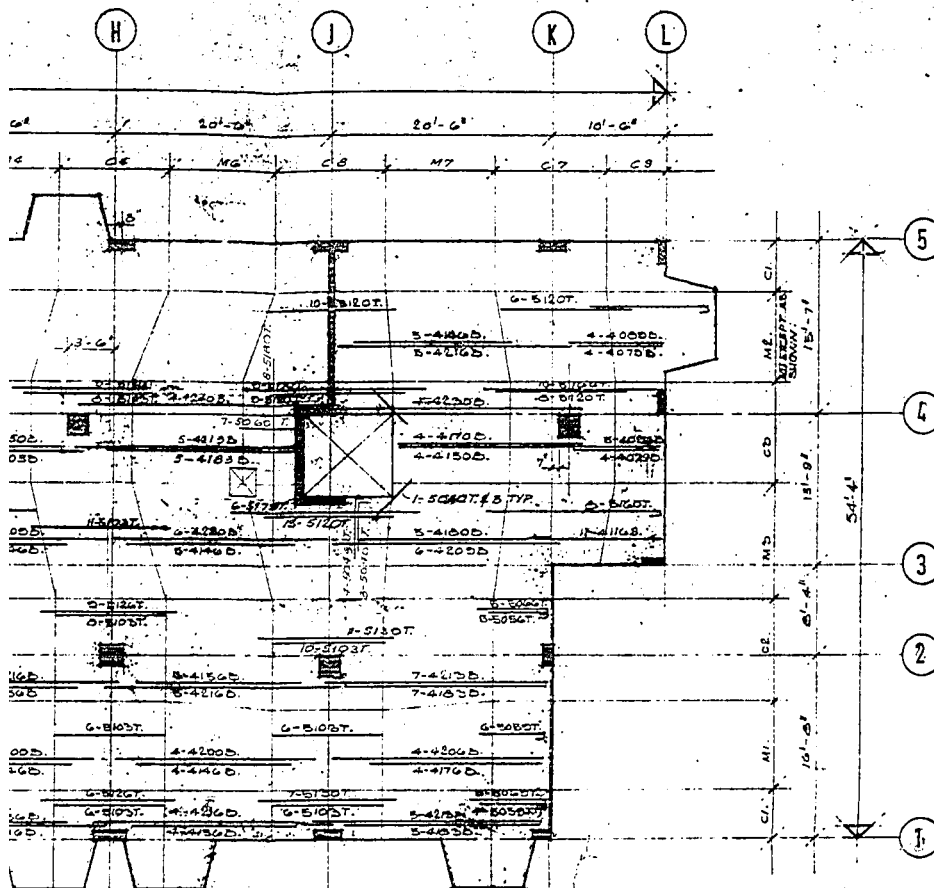


ABSOLUTE MAX. L.R. = 1.70
CONVERGED MAX. L.R. = 1.72 (< 2).

APPENDIX 7

PLAN OF THE TYPICAL FLOOR OF THE APARTMENT
BUILDING AT ALTA VISTA DRIVE, OTTAWA





SECTION 3
SCALE: 3/8" = 1' - 0" 52.54

DATE :
BY :
REVISION NO. :

REVISIONS

NOTES

DIMENSIONS SHOWN ON THESE DRAWINGS SHALL NOT BE USED FOR CONSTRUCTION UNTIL THEY HAVE BEEN CHECKED AGAINST FINAL ARCHITECTURAL AND MECHANICAL DRAWINGS BY THE GENERAL CONTRACTOR.

1. DESIGN LOADS

DESIGN LOADS	EXTERIOR BAY	INTERIOR BAY
8" SLAB	100	100
CEILING	5	5
PARTITIONS	10	20
DL.	115	125
LIVE LOAD	40	40
	155	173

2. BAR PLACING ORDER

- PLACE 1. BOT BARS
2. " "
3. TOP "
4. " " "

3. FOR COLUMNS LINE (3), MAINTAIN CONSTANT LOCATION OF FACE OF COLUMN AS DIMENSIONED ON PLAN (COLUMN SIZE VARIES FLOOR TO FLOOR).
4. MASONRY REINFT. FOR 8" BLOCK WALLS & STAIR & ELEVATOR SHAFTS TO BE #5 @ 48" C/C (VERT) AND DUE-0-WALL OR BLDG-LOK WITH 9 GA. DEFORMED SIDE RODS @ 16" C/C (HORIZ).
5. FOR MECH. DUCT OPENING SIZE SEE MECH. DWGS. PROVIDE 1-5040 TOP & BOT DIAG. CORNER BARS AT OPENINGS.

THE ELITE

ASSOCIATES

ACISTUC

OTUMBA ONE

ARCHITECT

ALA-KANTTI /LIF

STEFANISZYN

PROJECT \

ALTA VISTA DRIVE

APL BUILDING

12

9:11ALAL FLOOR 1

Appendix NO. 8.

PLAN OF THE TYPICAL FLOOR "PLACE DU PORTAGE" HULL, QUEBEC.